JV TASK 104 – RISK REDUCTION USING INNOVATIVE VACUUM-ENHANCED PLUME CONTROLS

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DISCLAIMER

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ABSTRACT

The Energy & Environmental Research Center (EERC) conducted remediation of hydrocarbon-contaminated soils and groundwater at the Vining Oil site in Carrington, North Dakota. The primary technological synergies included 1) contaminant recovery using simultaneous operation of multiphase recovery and high-vacuum soil vapor extraction (SVE) and 2) vacuum-controlled air and ozone sparging on the periphery of an induced hydraulic and pneumatic depression. Final risk reduction steps included design and retrofit for the municipal well. The successful remediation effort resulted in the reduction of long-term health risks associated with rate-limited contaminant release within the capture zone for the municipal well and allowed for its reintegration into the water supply system.

Contaminant recovery for the remediation period of September 2006 to June 2008 totaled over 12,653 lb (5,740 kg) of hydrocarbons, an equivalent to 2022 gallons (7653 l) of product. Integration of the air-sparging subsystem operated simultaneously with multiphase extraction and SVE systems resulted in accelerated volatile organic contaminant transport from the saturated zone and increased contaminants of concern recovery. Delivery of over 7.7 million ft^3 of oxygen (219.8 thousand m^3) into the contaminated aquifer would translate into in situ biodegradation of 2007 kg (4424 lb) of benzene and provide for long term stimulation of the natural attenuation process.

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EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC) conducted remediation of hydrocarbon-contaminated soils and groundwater at the Vining Oil site in Carrington, North Dakota. The primary technological synergies included 1) contaminant recovery using simultaneous operation of multiphase recovery and high-vacuum soil vapor extraction and 2) vacuum-controlled air and ozone sparging on the periphery of an induced hydraulic and pneumatic depression. Final risk reduction steps included design and retrofit of the municipal well.

A total of 2,425,516 gallons (9,180 m^3) of groundwater and 61.2 million ft^3 (1.7 million m^3) of soil vapor have been extracted from well fields from September 2006 to June 2008, resulting in the removal of over 12,604 lb (5,720 kg) of hydrocarbons prior to stripping and an additional 49.2 lb (22 kg) from the treated groundwater. The mass of recovered contaminant equals approximately 2022 gal (7,653 l) of product.

Integration of the air-sparging subsystem resulted in accelerated volatile organic contaminant (VOC) transport from the saturated zone and increased contaminants of concern (COC) degradation. Delivery of over 7.7 million ft^3 of oxygen (219.8 thousand m^3) into the contaminated aquifer would translate into in situ biodegradation of 4424 lb (2007 kg) of benzene and provide for long-term stimulation of the natural attenuation process.

Postremediation samples confirmed that concentrations of target contaminants in all monitoring and process wells at the site were reduced below detection limits or exhibit steadily declining trends; repeated samples from the municipal well confirmed nondetect levels for the target contaminant. The successful remediation effort resulted in the reduction of long-term health risks associated with rate-limited contaminant release within the capture zone for the municipal well and allowed for its reintegration into the water supply system.

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1.0 INTRODUCTION

At the request of the North Dakota Department of Health (NDDH) and the North Dakota Petroleum Tank Release Compensation Fund (NDPTRCF), the Energy & Environmental Research Center (EERC) conducted remediation of hydrocarbon-contaminated soils and groundwater at the Vining Oil site in Carrington, North Dakota. Rate-limited release of residual hydrocarbons in complex geotechnical conditions presented a long-term risk for the Carrington water supply system.

The overall objective of the remediation activities was to design and implement vacuum-mediated recovery of residual contaminants and acceleration of their in situ degradation. The primary goal was to reduce contaminant concentration levels in soils and groundwater to below acceptable regulatory limits and eliminate their migration to the municipal well.

This report presents a summary of results including a description of technologies applied. More detailed information, original data sets, and primary documentation are compiled in technical progress reports provided to the sponsors and regulatory agency on a quarterly basis. The project was sponsored by NDPTRCF and the U.S. Department of Energy (DOE) and supervised by NDDH.

2.0 EXPERIMENTAL

The remedial strategy at the subject site was based on an innovative combination of remediation systems designed to overcome challenging geotechnical conditions (multilayered environment, capture zone for municipal well field). The primary technological synergies included 1) contaminant recovery using simultaneous operation of multiphase recovery and high-vacuum soil vapor extraction (SVE) and 2) vacuum-controlled air and ozone sparging on the periphery of hydraulic and pneumatic depression induced by simultaneously operating recovery systems. Final risk reduction steps included design and retrofit of the municipal well based on a high-resolution camera survey.

Definition of the contaminated target zone, contaminant properties, and the results of the EERC pilot test indicated that remediation technology or a combination of technologies suitable for the subject site has to be capable of:

- Efficiently removing contaminants from both the vadose and saturated zones in multilayered heterogeneous sediments with extremely variable hydraulic properties.

- Being flexible enough to address water table fluctuation across the contaminant smear zone.

- Providing for accelerated oxidant supply to stimulate in situ contaminant oxidation.

- Creating an effective sparging zone to intercept the contaminant migration pathway between the source and municipal well.

- Enhance oxygen delivery to stimulate in situ biodegradation processes.

Additional objectives and requirements for this demonstration were:

- A well field design that would not be disruptive to traffic and daily operation of facilities at the site.
- A flexible operational schedule for the remediation systems that would be complementary to operation of the municipal water supply system.

3.0 RESULTS AND DOCUMENTATION

3.1 Site Characteristics

3.1.1 Site Location and Contaminant Release History

The original source area at Vining Oil Company, Inc., 375 Highway 281 NE, T146N R66W Section 18, Foster County, Carrington, North Dakota, is approximately 150 × 150 ft; the inferred extent of contamination based on contaminants of concern (COC) in monitoring wells was at least 200 × 250 ft. The impacted area overlaps the capture zone for the northern well of the municipal water supply system located southeast of the site, with benzene concentrations in raw water exceeding 35 µg/l (NDDH monitoring data from January 20, 2006). The site layout is provided in Figure 1.

The gasoline odor in the municipal well was reported by the City of Carrington in August 1987. Following the replacement of three underground storage tanks (USTs), the site has been under NDDH monitoring since 1987. The persistent presence of untreated contaminant source within the capture zone for the municipal well prompted UST removal and excavation of the petroleum-contaminated soils in 1997. At that time, Vining Oil began operation of plume intercept/recovery well MW-8. Repeated occurrence of benzene above U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs) in drinking water and its increasing trends have been documented since 1987.

3.1.2 Geotechnical Conditions

The geology of the impacted area is dominated by a heterogeneous complex of sandy silts interbedded with layers of silty clays to 20–25 ft that overlay sands of the Carrington Aquifer. The sediment profile consists of 8–15 ft of sandy silts and fill material in the area of removed USTs underlain by a 2–3-ft-thick layer of hard compacted clay with shale and coal inclusions. Silty clays with the increasing presence of sand are documented from 15 to 23 ft. Poorly sorted sands from 23 ft belowground represent the upper part of the sandy and gravelly Carrington Aquifer.

Depth to water at the subject site, including extraction wells, ranged from 22.68 ft to 32.30 ft belowground during the monitoring period of August 2006 and December 2008. The water table in the perched saturated layer above the main aquifer fluctuated between 9 and 11 ft belowground. While regional groundwater flow in an unconfined Carrington Aquifer is to the northeast (interpretation based on North Dakota State Water Commission data), the prevailing direction of groundwater flow in the target area is south–east–south in response to long-term

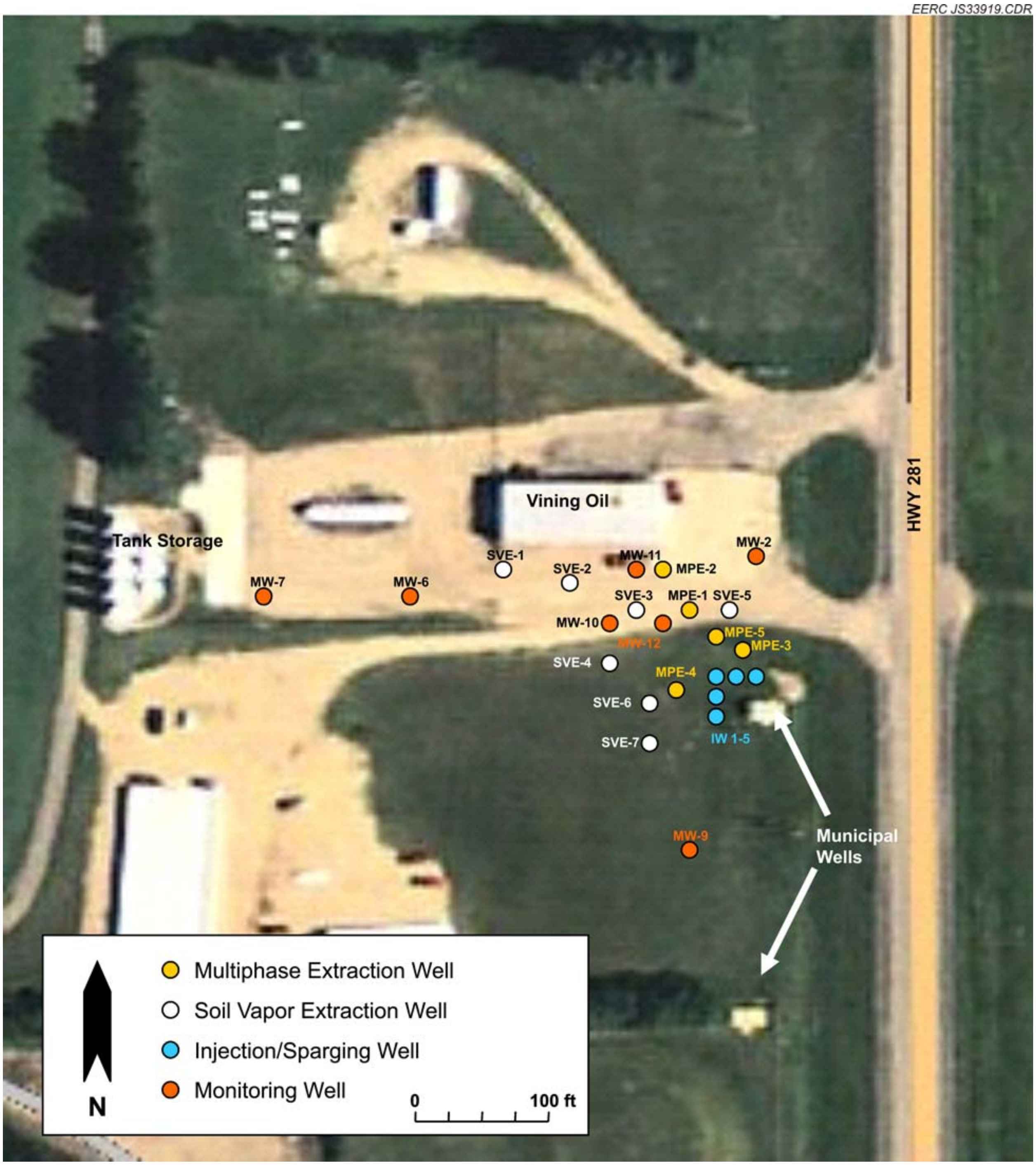


Figure 1. Site plan.

pumping from two municipal wells. The entire target area lies in the capture zone for the northern municipal well intermittently operated at 800 gpm, resulting in drawdown of 25–30 ft.

Groundwater chemistry is dominated by calcium and bicarbonate ions with an extremely high concentration of iron (9.9–114 mg/l in monitoring wells, 11.9 mg/l in extraction well REC-1), hardness of 458 mg/l, and electrical conductivity (EC) of 0.7–1.0 mS/cm. Slightly increased biological oxygen demand (BOD) was documented from contaminated wells [1, 2].

3.1.3 Contaminant Transport

Contaminant released from leaking USTs followed a simple gravity-controlled path through the vadose zone until its flow was partially obstructed by a layer of hard compacted clay intercepted at 8–15 ft belowground. Both the laser-induced fluorescence (LIF) and drilling confirmed increased COC presence at the top of this clayey layer; however, its continuous development across the site was not confirmed. Discontinuities in the noted layer allowed for further vertical migration of COC to the aquifer. Once the COC reached the water table, its further migration was controlled and likely accelerated by pumping from the municipal wells and, later, by extraction from the recovery/intercept well (retrofitted to MPE-5).

Most of the petroleum-based residual COC are typically trapped within the upper portion of the aquifer, which is subject to natural fluctuation. With respect to the source location within the capture zone of the city well, however, a high pumping rate (800 gpm), about 30 ft drawdown, and long-term use of the municipal well could have resulted in a smear zone as thick as 20–30 ft in the area immediately adjacent to the city well.

Current information on contaminant properties (gasoline), groundwater-table fluctuation (25–30 ft belowground), drawdown caused by pumping (up to 50 ft belowground), and the screen interval documented by NDDH at 70–90 ft belowground did not provide an explanation for COC migration into the municipal well.

Because of the complete absence of well construction documentation for the impacted municipal wells, the pump was removed and the well was put off line in June 2006. A camera survey was conducted to evaluate the current technical condition of the well and to define zones/points of entry for potential COC migration into the well. It was assumed that the point of entry for (LNAPL) is either within the smear zone and corresponds with damaged or leaking casing or via hydraulic communication between the deep recovery (former MW-8 backfilled and retrofitted as MPE-5) and municipal well. The survey was conducted using a direct-operated Inuktun Crystal Cam® camera. The results provided in DVD format illustrate that the original well casing consisted of 4-ft-long, 16-in.-diameter concrete rings to the top of the concrete screen at 76 ft. The screen between 76 and 91 ft was completed of 4-ft-long and 16-in.-wide well-preserved slotted concrete sections. Casing joints and minor offsets between 30 and 50 ft including casing discoloration and intensive incrustation along the joints corresponding with the dynamic water table during pumping at depths below 50 ft (reported drawdown in response to well operation) and mainly 55–68 ft (highly oxidized area corresponding with turbulence next to the pump intake) indicated possible leaks through joints along the entire casing profile. Based on results of the camera survey, a well retrofit was designed to eliminate the potential for casing leaks within the smear zone.

3.2 Remediation Systems

3.2.1 Extraction, Monitoring, and Injection Well Fields

The extraction and monitoring well field was completed August 2–7, 2006, and, together with existing wells at the site, consists of five (5) multiphase extraction wells (MPE) and seven (7) SVE wells. Five (5) air/ozone-sparging wells were completed on the northwestern perimeter of the municipal well housing. Because of the potential for cross-contamination and unnecessarily high recovery rates required to achieve drawdown in deep intercept well MW-8, this well was backfilled to 34 ft, converted into extraction well MPE-5, and linked to the recovery system. Selected monitoring wells were equipped for vacuum pressure and water-level monitoring (MW-2, MW-10, MW-11, and MW-12). The well field and trenching layout is provided in Figure 1 and Appendix A.

Based on results of the feasibility study, the final extraction well field was designed to overcome site heterogeneities, uncertainties related to performance of retrofitted old well MW-8, and a primary requirement for the radii of influence to overlap with the impacted capture zone for the municipal well. The final well field allowed for maximum flexibility and water-table control and provided for dewatering of the contaminant smear zone, thus allowing air to be a primary carrier for contaminant removal.

Extraction well boreholes were advanced by a 6-in.-i.d. (10-in.-o.d.) hollowstem auger using a CME 75 drill rig. MPE wells are completed with 4-in.-diameter flush-threaded PVC, Schedule 40, with a 0.020-in. slot screen and No. 30 red flint pack. Extraction wells are equipped with 1-in. PVC suction tubes extending 4 ft below the water table (at the time of operation). SVE and sparging wells were completed with 2-in.-diameter flush-threaded PVC, Schedule 40, with a 0.010-in. slot screen and No. 30 pack. All MPE and selected monitoring wells were further equipped with pressure and water-table-monitoring ports with a ¾-in. drop tube extending to <1 ft from the bottom of the well. All SVE and sparging wells were equipped with pressure-monitoring ports. Well completion data including geologic and survey logs are provided in the Technical Progress Report for July–September 2006 [2].

3.2.2 Remediation and Treatment Systems

The MPE and treatment system consisted of a Busch MM 1322 AV rotary claw 10-hp vacuum blower rated for 200 acfm and end vacuum of 28.4-in. Hg. Recovered water and air passed through the 60-gal vapor–liquid separator (VLS) to the oil–water separator (OWS) with an integrated product storage tank. Water from the OWS overflowed and was then alternatively pumped to a low-profile QED LP-2.4P air stripper, Birm™ iron reduction system, and integrated aftercooler. Effluent water from the air stripper was conveyed to the drainage ditch.

The SVE package consisted of a regenerative blower rated at 180 scfm and 5.9-in. Hg, VLS, and liquid transfer pump to the OWS. The air-sparging package included an SR-32 ozone generator, water-cooled aftercooler, and 7.5-kW blower rated at 70 cfm and 22 psi. The entire system was equipped with a NEMA 4 controller, modem, and Internet-accessible telemetry package via digital subscriber line (DSL), allowing for both on-site and telemetric control of individual system units, including assignments of alternating well fields (zone assignment), their timing, and monitoring.

3.2.2.1 System Performance Monitoring and Sampling

The MPE and treatment system started break-in operation on August 31, 2006. After system optimization, full-scale operation commenced September 19, 2006, and continued until June 17, 2008. System performance monitoring and effluent water and offgas sampling were conducted on a monthly basis; telemetric system control and download were conducted daily throughout the operation. Basic operational parameters are summarized in Table 1.

Table 1. MPE System Operational Parameters

Well Fields	MPE– 1, 2, 3, 4, 5; SVE – 1, 2, 4, 6, 7
Well Fields Operated (date)	9/19/06–6/17/08
Blower Vacuum (in. Hg)	20.5–24
Wellhead Vacuum (in. H_2O)	42–181
Groundwater Flow (gpm)	3.5 (0.7–8.7)
Groundwater Recovered – total (gal)	2,425,516
Combined Airflow (scfm)	39.7–95.4
Run Time – total (h) (operation %)	14,970 (98%)
Down Time – total (h)	342.7

3.2.2.2 System Water Quality

Samples of extracted water and treated effluent were analyzed for COC (benzene, toluene, ethylbenzene, xylenes, [BTEX] phenols, and total petroleum hydrocarbons [TPH] as gasoline range organics [GRO]), total iron and manganese, and suspended solids. Field measured parameters included pH, EC, and temperature.

Contaminant recovery from the extraction well fields exhibited declining trends from TPH and BTEX values of 7.5 mg/l and 2.6 mg/l, respectively, to nondetect levels before system shutdown. It is important to note that initial benzene concentrations in wells adjacent to the municipal supply well exceeded the drinking water limit of 5 µg/l by a factor of 1000. A summary of extraction and treatment data is provided in Appendix C-1; complete analytical documentation is in the respective technical progress reports. A 100% water treatment system efficiency was achieved for BTEX removal.

3.2.2.3 Offgas Quality

Offgas quality from combined exhaust was monitored using charcoal tubes and real-time monitoring of hydrocarbons, CO_2, and O_2 using a photoionization detector (PID), a flame ionization detector (FID), and a Summit hydrocarbon analyzer.

Offgas-sampling results using charcoal tube desorption and analyzed by gas chromatography (GC)/FID are summarized in Appendix C-2. VOC concentration trends are provided in Figure 2. To overcome fluctuating airflow velocities typical of MPE systems, offgas was collected in a 1-l Tedlar bag at a rate of approximately 0.3 l/min. Charcoal tube samples were subsequently collected directly from the Tedlar bag using an SKC pump with flow regulated at 0.28 l/min. In addition, carbon dioxide and oxygen trends in extracted vapors were

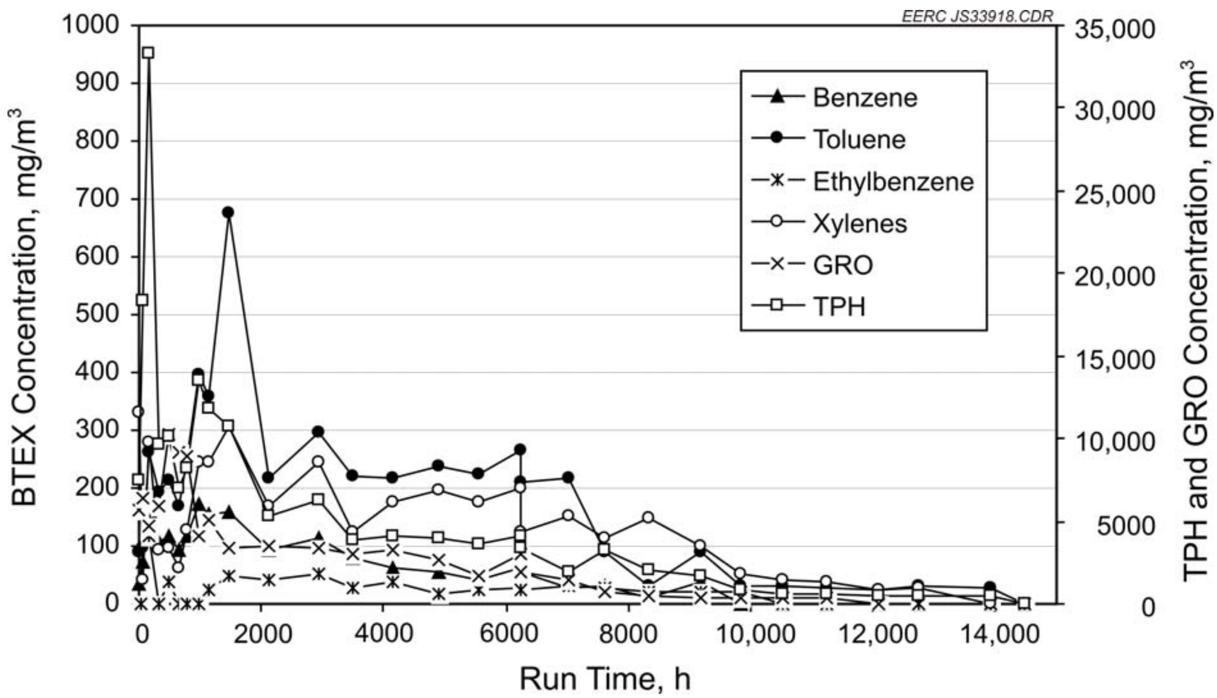


Figure 2. Hydrocarbon concentration trends in offgas (values represent average between two consecutive samples).

monitored using the Summit analyzer. The mass balance for recovered VOCs and average emission loads was calculated based on results of offgas analyses and average exhaust airflow corrected to standard conditions and reported to NDDH on a quarterly basis.

Volatile organic compounds (VOC) concentrations peaked at 33,000 mg/m^3 (TPH) and 1200 mg/m^3 for BTEX during the first months of extraction and followed an expected steady decline during the extraction system operation. VOC emissions in offgas declined from the highest levels of 1.1 lb/h within several weeks of operation and were well below the NDDH required limit for VOCs of 16 lb/hr.

3.2.2.4 Hydraulic and Pneumatic Response

Groundwater-table monitoring at the extraction and monitoring wells was conducted on a monthly basis during operation of remediation systems. Depth to water at the subject site, including extraction wells, ranged from 22.68 ft to 32.30 ft belowground during the monitoring period of August 2006 and December 2008. The water table in the perched saturated layer above the main aquifer fluctuated between 9 and 11 ft below ground. Drawdown measured at extraction wells of up to 5.4 ft resulted in intermittent well dewatering. Because of the high hydraulic conductivity of the aquifer, water-table decline on monitoring wells was minimal and recorded a more pronounced decline only during operation of the municipal well. Induced depression in response to MPE operation resulted in reversed gradient toward the extraction well field.

Monitoring the vacuum pressure at the extraction and monitoring wells was conducted on a monthly basis. Extraction well vacuums ranged from 42 to 181 in. H_2O (Appendix C-4) and resulted in up to 5 ft of water-table drawdown or temporary dewatering of extraction wells. Pneumatic impact of the extraction well field was observed as far as 65–80 ft (MW-2) from the center of the extraction well field, with radii of influence for individual wells up to 70 ft. The start-up of the sparging system in June 2007 correlated with pressure buildup across the impacted formation observed as far as 80 ft (MW-2) from the sparging field and resulted in highly variable pressure/vacuum response at individual wells. With the exception of the immediate vicinity of simultaneously operating MPE and SVE wells, pneumatic response to air sparging was more pronounced than vacuum response to extraction and spread across the monitored area. Water level records and vacuum-monitoring data are summarized in Appendices C-3 and C-4; detailed response maps are provided in quarterly technical progress reports.

3.2.3 Air-Sparging System

The air-sparging system started break-in operation in June 2007. Full-scale operation commenced July 11, 2007. System performance evaluation consisted of monitoring of injection pressure, temperature, and airflow for individual sparging wells, including sitewide pressure response on monitoring and extraction wells (Appendix C-4). Ozone injection for in situ oxidation of residual hydrocarbons was initiated on May 13, 2008, in wells IW-3, IW-4, and IW-5 and operated until September 2, 2008. Ozone was injected into the air-sparging stream at a rate of 2–3 lpm per well. Basic operational parameters and mass balance estimates for the injection system are summarized in Table 2 and Appendix D, respectively.

Table 2. Air-Sparging System Parameters

Well Field	IW–1, 2, 3, 4, 5
Well Field Operated (date)	7/11/07–12/10/08
Injection Pressure (psi)	10.5–15.5
Injection Air Temperature (ºF)	72–195*
Combined Airflow (scfm)	34–59
Run Time – total (h) (operation %)	21,174 (97.9%)
Down Time – total (h)	267

* Temperature increase after MPE system and aftercooler shut down.

3.3 Contaminant Recovery and Degradation Estimates

A total of 2,425,516 gallons (9,180 m^3) of groundwater and 61.2 million ft^3 (1.7 million m^3) of soil vapor have been extracted from well fields since start-up on September 18, 2006, and system shutdown on June 16, 2008, resulting in removal of over 12,604 lb of hydrocarbons prior to stripping and an additional 49.2 lb from the treated groundwater. The mass of recovered contaminant equals approximately 2022 gal of product, assuming specific gravity for gasoline of 0.75 g/cm^3. The average liquid flow rate since system start-up was approximately 3.5 gpm, ranging from 0.7 gpm (winter operation) to 8.7 gpm; the airflow rate ranged from 40 scfm to 95 scfm. Data for mass removal calculations are provided in Appendix D; cumulative recovery is presented in Figure 2. Results of the short-term extraction rebound test conducted from June 17 until July 15 indicated nondetect COC levels in extracted groundwater and vapors. Contaminant recovery/degradation breakdown is provided in Table 3. It is apparent that MPE technology using air as the primary contaminant carrier by far exceeds the COC recovery and degradation efficiency of conventional pump-and-treat systems.

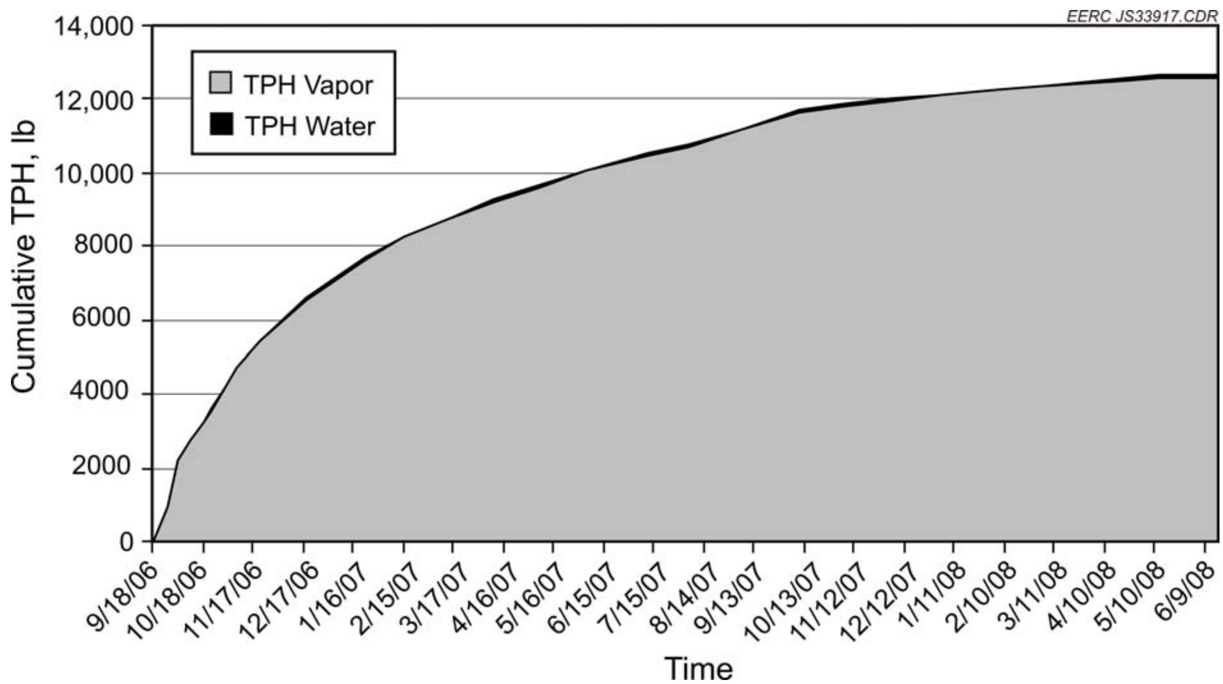


Figure 3. Total hydrocarbon removal by MPE.

Over 36.9 million ft^3 of air (1.4 million m^3), including 7.7 million ft^3 of oxygen (219.8 thousand m^3), was injected into the contaminated aquifer during operation of the air-sparging system (ozone sparging is not considered). Assuming limited oxygen transfer efficiency in the saturated zone of 2% [3], the injected volume of oxygen would translate into in situ biodegradation of an estimated 4424 lb (2007 kg) of benzene (based on simplified stoichiometry for electron donors, i.e., petroleum hydrocarbons, and electron acceptors, a reduction of 1 mg/l of dissolved oxygen consumed by microbes results in biodegradation of 0.32 mg/l of benzene). The remaining 98% of oxygen is available for COC oxidation in the vadose zone and VOC transport into SVE and MPE controlled zones. A summary of air-sparging system performance is provided in Appendix D.

In addition to contaminant recovered by extraction and reduced by in situ biodegradation as a result of nutrient injection, a total of 22,900 lb (10,387 kg) of oxygen was delivered to the saturated zone during operation of the MPE system, assuming 2% oxygen transfer efficiency and 61.2 million ft^3 (1.7 million m^3) of soil vapor exchanged/recovered. By providing the necessary electron acceptor and using the same stoichiometry as for injection estimates, this volume translates into further in situ reduction of 7328 lb (3,324 kg) of contaminant. Because quantification of in situ contaminant reduction is extremely difficult (Section 3.5), results of degradation via oxygen delivery (air sparging, soil vapor exchange) presented in Table 3 are not considered in total mass balance.

Table 3. Contaminant Recovery/Degradation Breakdown Estimates

COC Recovered/Degraded	Total (lb)	(kg)	(gal)	(%)
Vapor Extraction	12,604	5720	2014	51.6
Groundwater Extraction	49	22	8	0.2
Degradation by Air Sparging (O_2 delivery)	6271	2007	707	18.1
Degradation by MPE/SVE Air Exchange (O_2 delivery)	7328	3324	1171	30.0
	26,252	11,073	3900	100

3.4 Groundwater Quality Monitoring

3.4.1 Sampling Program

Monitoring and extraction wells were sampled for BTEX, GRO, and biodegradation indicators on a semiannual basis to document overall remediation system impact on groundwater quality compared to original site data collected in August 2006 (prior to system start-up). The final sampling was conducted on October 30, 2008.

Groundwater samples were collected using disposable PVC bailers, preserved on-site, and stored on ice prior to and during shipment. Analyses were conducted by MVTL in Bismarck, North Dakota, and New Ulm, Minnesota. Quality assurance/quality control samples included duplicates, equipment blanks, field blanks, and trip blanks for each sampling event. Field-monitored water quality parameters were measured in wells with an YSI-556 multiparameter probe.

3.4.2 Water Quality Trends

Concentrations of target contaminants were reduced to below detection limit in all extraction and monitoring wells at the site. Residual benzene concentrations exhibit steadily declining trends in sparging wells IW-4 and IW-5, where over 94% benzene reduction was achieved (initial benzene concentrations exceeded the drinking water limit of 5 µg/l by a factor of 1000). Concentrations of toluene, ethylbenzene, and xylene in these wells were successfully reduced to regulatorily acceptable limits of 1000 ppb, 700 ppb, and 10,000 ppb, respectively.

Residual COC levels are above limits in SVE wells 1, 2, 4, and 6 completed in a hard, compacted, silty-clayey layer that seasonally retains recharged water in an initially contaminated perched aquifer. Originally dry SVE wells contain water that is exposed to rate (diffusion)-limited COC release from the noted compacted clays. With respect to rate-limited release from sediments that are not in direct contact with the aquifer, pathway interception, and municipal well relining, the potential for COC migration to the well is low. Samples collected from the municipal well after two years of remediation system operation and well relining exhibit nondetect levels for target contaminants.

Biodegradation indicators do not exhibit any pronounced trends that would support conclusions on active biodegradation. The aquifer and its impacted portion are aerobic, with low concentrations of primary electron acceptors (oxygen, nitrate, phosphorus, and sulfate) and only slightly increased BOD values in contaminated wells. A summary of groundwater analyses including data from monitoring of biodegradation indicators is provided in Appendix E.

3.4.3 Municipal Well Monitoring

Reduction of COC in monitoring wells across the site, asymptotic recovery trends, and relining of the municipal well allowed for well testing and reintegration into the supply system. Well North was monitored in coordination with NDDH and the Water Treatment Plant in Carrington. The first test sample was collected after well retrofit in April, 2008. Following the MPE system shutdown, samples from the municipal well were collected during well operation from June to December 2008 on a monthly basis to evaluate potential qualitative changes related to pumping time/withdrawal volume and water table depression. NDDH collected samples during the same coordinated sampling events (Appendix C). Results of sampling confirmed nondetect levels for COC (Appendix E-1).

3.5 Technical and Economic Summary and Discussion

The remedial strategy was based on innovative technological synergies including 1) contaminant recovery using simultaneous operation of multiphase recovery and high-vacuum SVE and 2) vacuum-controlled air and ozone sparging on the periphery of induced hydraulic and pneumatic depression. The MPE system was successfully operating 98% of the time, including monthly maintenance shutdowns, between September 19, 2006, and June 17, 2008.

The high contaminant removal efficiency of MPE technology is a result of a combination of simultaneous extraction of water and vapor. It follows from contaminant recovery/degradation breakdown estimates (Table 3) that vapor extraction efficiency by far exceeds that for groundwater (in this case by a factor of 263) and, to a certain extent, draws a comparison between SVE and pump-and-treat systems. Documented high contaminant recovery using vapor as a primary carrier could not, however, be achieved without simultaneous dewatering of the targeted smear zone.

An additional advantage of MPE is air exchange/oxygen delivery to the contaminated zone during operation of the MPE system. Because quantification of in situ oxygen partitioning between soil- and groundwater-bound contaminants and their subsequent reduction is extremely difficult, this means of degradation, albeit substantial, is often not considered by the environmental industry in mass balance estimates. Similarly, estimates for VOC oxidation and in situ degradation resulting from oxidant delivery into the contaminated aquifer via sparging systems conservatively assume only 2% oxygen transfer efficiency [3]. As such, these mass balance and degradation estimates may be subject to large interpretive variability.

Based on project cost and total contaminant recovery of 12,653 lb per unit, the cost for contaminant recovery was $61/lb ($134/kg). If in situ degradation resulting from oxygen delivery is considered (and in spite of its difficult quantification, it is a critically important part of the remediation process), the cost would be $29.40/lb ($69.70/kg) of recovered/degraded contaminant. These relatively high costs do not include postmonitoring and site restoration activities but have to be considered in the context of costs associated with replacement of the municipal well (~ $200,000), its integration into water supply system, and limited geotechnical options for locating new well capable of replacing equivalent water supply capacity.

4.0 CONCLUSIONS

A total of 2,425,516 gallons (9,180 m^3) of groundwater and 61.2 million ft^3 (1.7 million m^3) of soil vapor have been extracted from well fields from September 2006 to June 2008, resulting in removal of over 12,604 lb (5,720 kg) of hydrocarbons prior to stripping and an additional 49.2 lb (22 kg) from the treated groundwater. The mass of recovered contaminant equals approximately 2022 gal (7,653 l) of product.

Integration of the air-sparging subsystem resulted in accelerated VOC transport from the saturated zone and increased COC degradation. Delivery of over 7.7 million ft^3 of oxygen (219.8 thousand m^3) into the contaminated aquifer would translate into in situ biodegradation of 4424 lb (2007 kg) of benzene and provide for long-term stimulation of the natural attenuation process.

Results of groundwater sampling conducted in September/October 2008 indicated that concentrations of target contaminants in all monitoring and process wells at the site were reduced below detection limits or exhibit steadily declining trends. Analytical results for both the EERC- and NDDH-collected samples from the municipal well confirmed nondetect levels for the target contaminant.

Remediation effort at the site resulted in contaminant reduction and improvement of groundwater quality within the capture zone for the municipal well. It is, therefore, recommended to proceed with integration of municipal well North into the existing water supply system. In order to protect the aquifer and prolong the life of the well, it is further recommended to consider modification of the water withdrawal strategy. Using lower pumping rates for a longer pumping period would provide the same amount of water while minimizing negative effects of deep temporary drawdown associated with high discharge rates.

5.0 REFERENCES

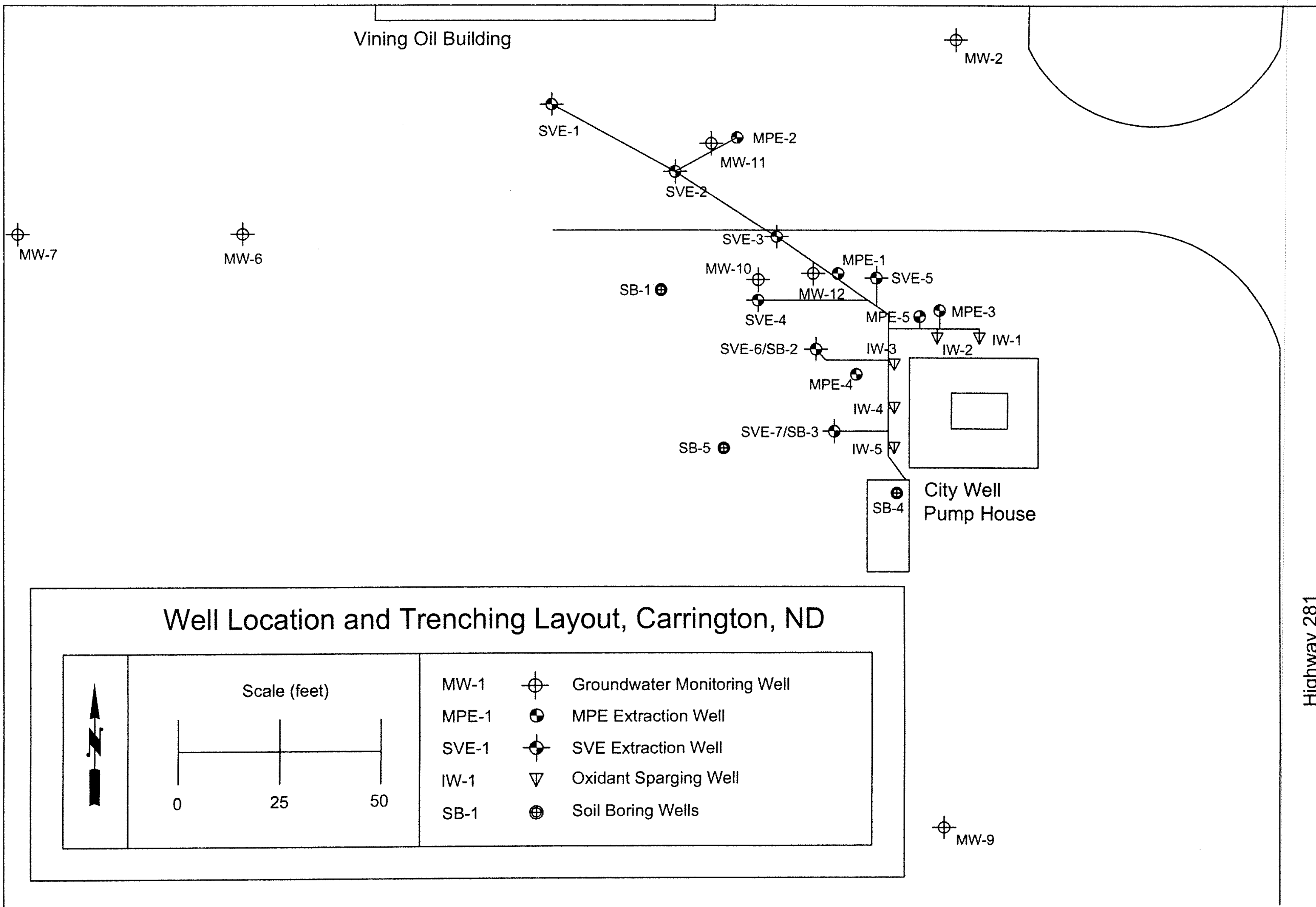
1. Solc, J., and Botnen, B.W., 2006, Feasibility of accelerated risk reduction using innovative vacuum-enhanced plume controls: Carrington, North Dakota: EERC final report.

2. Solc, J., and Botnen, B.W., 2006, Risk reduction using innovative vacuum-enhanced plume controls: Technical Progress Report: July–September, 2006, Grand Forks, North Dakota, Energy & Environmental Research Center.

3. Kuo, J., 1999, *Practical design calculations for groundwater and soil remediation*: Boca Raton, Florida, CRC Press, LLC Lewis Publishers.

APPENDIX A

EXTRACTION AND INJECTION WELL FIELDS



Well Location and Trenching Layout, Carrington, ND

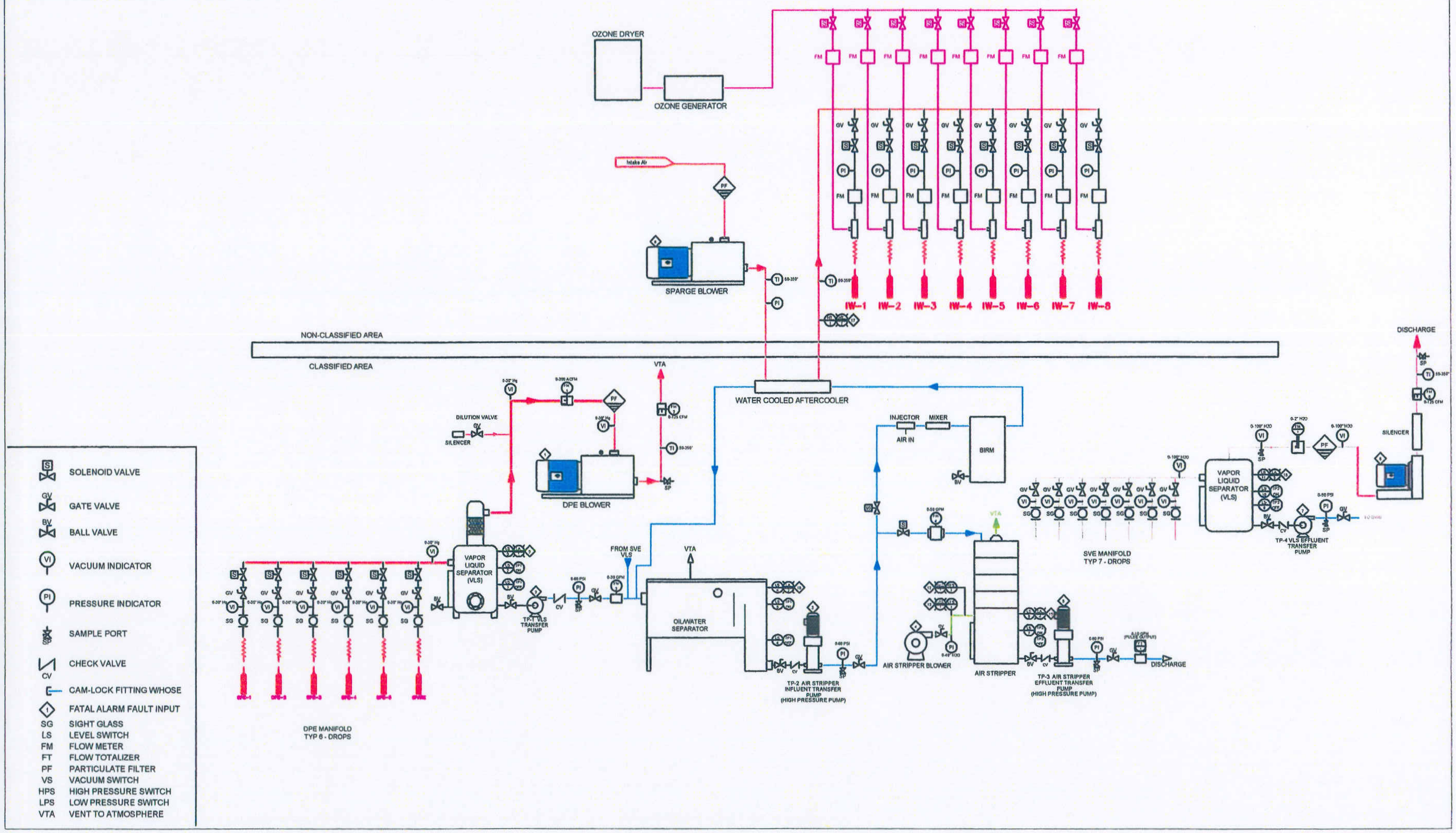
Well Completion Summary

Well ID	Northing	Easting	Elevation TOC (ft)	Elevation Ground (ft)	Drilled Depth (ft)	Screen Interval (ft)	Gravel Pack Interval (ft)	Seal Interval (ft)	Grout Interval (ft)	Dia. (in)
MPE-1	173597.207	2310343.439	1570.69	1571.14	33	22-32	20-32	0-20	0-20	4
MPE-2	173633.063	2310314.694	1570.86	1569.55	33	22-32	20-32	0-20	0-20	4
MPE-3	173575.771	2310360.705	1571.49	1571.74	34	23-33	21-33	5-21	5-21	4
MPE-4	173557.008	2310338.749	1571.60	1571.97	34	23-33	21-33	5-21	5-21	4
MPE-5	173574.699	2310354.727	1571.61	1571.88	34	26-35	20-35	0-20	0-20	6
MW-2	173651.708	2310374.833	1571.06	1571.24	39	24-39	23-39	22-23	0-22	2
MW-6	173604.660	2310175.732	1573.66	1571.31	38	28-38	27-38	26-27	0-26	2
MW-7	173608.056	2310050.737	1572.42	1569.99	38	23-38	20.5-38	19.5-20.5	0-19.5	2
MW-8	173574.699	2310354.727	1574.26	1572.17	80	26-74	NA	NA	0-20	6
MW-9	173430.982	2310352.092	1573.28	1571.52	40	30-40	29-40	28-29	0-28	2
MW-10	173591.375	2310319.569	1573.71	1571.76	33	22-32	20-32	0-20	0-20	2
MW-11	173632.049	2310307.484	1570.91	1571.27	33	22-32	20-32	0-20	0-20	2
MW-12	173594.583	2310336.779	1573.22	1571.58	33	22-32	20-32	0-20	0-20	2
SVE-1	173640.362	2310261.868	1570.94	1571.33	14	12.5-14	10-14	4-10	4-10	2
SVE-2	173622.665	2310297.754	1570.78	1571.27	14	12.5-14	10-14	4-10	4-10	2
SVE-3	173605.546	2310328.435	1570.74	1571.08	14	12.5-14	10-14	4-10	4-10	2
SVE-4	173585.805	2310318.998	1571.18	1571.66	14	12.5-14	10-14	4-10	4-10	2
SVE-5	173591.439	2310352.122	1570.84	1571.24	14	12.5-14	10-14	4-10	4-10	2
SVE-6	173564.046	2310327.212	1571.35	1571.78	14	12.5-14	10-14	4-10	4-10	2
SVE-7	173540.798	2310331.837	1571.42	1571.84	14	12.5-14	10-14	4-10	4-10	2
IW-1	173571.700	2310374.410	1571.27	1571.88	46	43.5-45	40-45	30-40	5-30	2
IW-2	173567.467	2310361.666	1571.61	1572.09	46	43.5-45	40-45	30-40	5-30	2
IW-3	173559.282	2310349.371	1571.62	1572.08	46	43.5-45	40-45	30-40	5-30	2
IW-4	173547.041	2310348.449	1571.68	1572.11	46	43.5-45	40-45	30-40	5-30	2
IW-5	173535.639	2310348.455	1571.67	1572.13	46	43.5-45	40-45	30-40	5-30	2

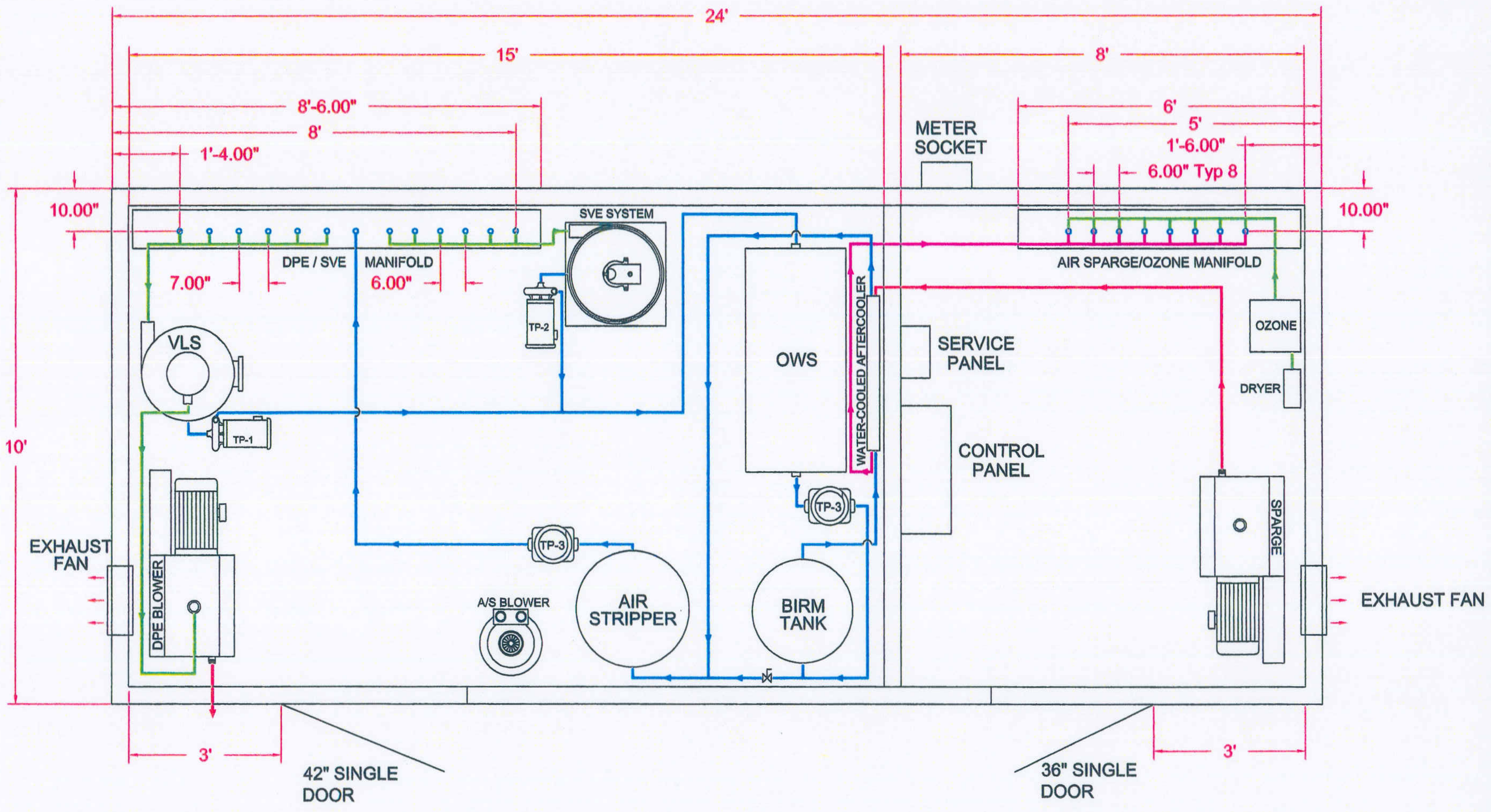
NA - information not available at this time

APPENDIX B

RECOVERY AND INJECTION SYSTEMS



TITLE: Process Flow and Instrumentation Energy & Environmental Research Center Carrington, ND-Vining Oil Project	DWN: MV CHKD: JS REV.: 3	DATE: 10/02/2006 DRAWING #: 738-P&ID



TITLE:	DWN: MV	DATE: 7/18/2006
EQUIPMENT LAYOUT EERC CARRINGTON, ND SITE	CHKD: SB REV.: 1	DRAWING #: EERC

APPENDIX C

SYSTEM MONITORING – SUMMARY OF DATA

APPENDIX C-1

WATER QUALITY

SYSTEM WATER QUALITY MONITORING

2006

VLS		**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**
		08/31/06	09/19/06	09/20/06	09/27/06	10/04/06	10/11/06	10/18/06	10/24/06	11/01/06	11/08/06	11/22/06	12/20/06
MTBE	ppb	<10	13	13.8	<10	<10	<20	<10	18.4	14.7	25.0	22.6	25.6
Benzene	ppb	114.9	276	319.4	326.2	338.1	357.9	354.5	359.8	351.3	394.0	334.4	285.2
Toluene	ppb	275.1	526.1	666.5	690.2	677.2	801.3	815.8	901.6	999.5	976.8	839	803.7
Ethyl Benzene	ppb	78.6	96.1	83.8	100.3	78.2	81.3	89.5	104.2	120.7	126.9	115.7	89.1
Xylenes (Total)	ppb	1866	1690	854.8	1152	636.6	678.8	651.8	775.9	844.7	865.5	820.5	841.3
GRO (TPH)	mg/l	6.65	7.53	5.68	6.43	4.31	5.15	4.62	4.6	5.4	5.2	4.7	4.0

Discharge		**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**
		08/31/06	09/19/06	09/20/06	09/27/06	10/04/06	10/11/06	10/18/06	10/24/06	11/01/06	11/08/06	11/22/06	12/20/06
MTBE	ppb	4.7	2	<1	<1	1.4	2.4	3.1	2.1	2.1	3.9	4.4	<1
Benzene	ppb	2.3	2.6	1.1	<1	2.5	1.9	3.1	2.9	1.5	1.7	<1	<1
Toluene	ppb	7.1	3.2	3.4	2.2	3.3	5.1	8.8	8.4	5.2	4.2	2.7	1.7
Ethyl Benzene	ppb	1.6	1.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Xylenes (Total)	ppb	71.9	17.4	6.4	5.9	<3	4.5	6.6	4.7	<3	4.2	<3	<3
Phenols (Total)	ppb	NA	26.2	29	71.1	38.8	NA	34.9	32.9	12	24	33.8	68.5
GRO (TPH)	mg/l	0.32	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

WATER QUALITY MONITORING

Selected Parameters		**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**	**VLS**
		09/19/06	09/20/06	09/27/06	10/04/06	10/11/06	10/18/06	10/24/06	11/01/06	11/08/06	11/22/06	12/20/06
pH		7.2	7.2	7.0	6.6	7.4	7.2	11.8	7.3	7.4	7.2	7.3
EC	µS/cm	877	901	692	970	795	912	780	736	690	699	766
T	°C	10	10.4	9.5	9.7	10.6	10.5	10.5	10.9	10.4	9.6	15.3

Selected Parameters		**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**	**Effluent**
		09/19/06	09/20/06	09/27/06	10/04/06	10/11/06	10/18/06	10/24/06	11/01/06	11/08/06	11/22/06	12/20/06
Fe (total)	mg/l	3.35	3.2	1.0	2.8	2.3	2.11	1.8	2.09	1.79	1.88	0.92
Mn (total)	mg/l	0.99	1.3	0.7	1.1	1.1	1.07	1.01	0.98	0.92	0.95	1.49
TSS	mg/l	4	3	6	21	6	17	2	6	5	10	15
pH		7.2	7.7	7.1	7.4	7.9	7.8	7.5	7.6	7.4	7.7	7.7
EC	µS/cm	870	871	671	807	772	794	954	870	678	668	685
T	°C	11.4	12.4	10.0	12.3	12.2	12.9	12.6	12.3	13.0	12.0	17.9

VLS-Vapor/Liquid Separator Sample Port

SYSTEM WATER QUALITY MONITORING

2007

VLS		VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS	VLS
		01/23/07	02/15/07	03/14/07	04/09/07	05/08/07	06/05/07	06/05/07	07/11/07	08/06/07	09/05/07	10/10/07	11/06/07	12/04/07
MTBE	ppb	22.6	17.8	12.2	12.1	<10	<10	<10	<10	<10	<10	<10	<10	1.5
Benzene	ppb	261.3	138.9	81.0	81.2	61.7	101.8	95.4	59.4	64.3	31.8	48.9	10.5	14.5
Toluene	ppb	800.5	591.1	394.1	427.1	372.4	604	340.5	528.8	205.7	92.8	172.7	50.1	68.5
Ethyl Benzene	ppb	82.9	61.9	39.2	46.5	36.3	65.6	65.5	59.1	56	55.2	12.9	<10	4.0
Xylenes (Total)	ppb	787	657.2	465.2	509.8	414.4	593.9	435.9	529.3	546.9	647.3	213.4	145.8	103.1
GRO (TPH)	mg/l	4.3	3.4	2.4	2.5	2.1	3.0	2.5	2.7	2.6	2.1	<2	0.9	0.8

Discharge		Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent
		01/23/07	02/15/07	03/14/07	04/09/07	05/08/07	06/05/07	06/05/07	07/11/07	08/06/07	09/05/07	10/10/07	11/06/07	12/04/07
MTBE	ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Benzene	ppb	1.3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	ppb	3.7	1	1.3	3.8	<1	1.3	<1	<1	<1	<1	<1	<1	<1
Ethyl Benzene	ppb	1.1	<1	1.3	<1	<1	1.1	<1	<1	<1	<1	<1	<1	<1
Xylenes (Total)	ppb	3.7	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Phenols (Total)	ppb	83	66.5	52.3	68	36.9	49.1	21.2	25.9	28.6	16.8	16.3	10.8	<10
GRO (TPH)	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

WATER QUALITY MONITORING

Selected Parameters		VLS	VLS	VLS	VLS	VLS	VLS1	VLS	VLS	VLS	VLS	VLS	VLS	VLS
		01/23/07	02/15/07	03/14/07	04/09/07	05/08/07	06/05/07	06/05/07	07/11/07	08/06/07	09/05/07	10/10/07	11/06/07	12/04/07
pH		8.3	7.8	8.4	7.9	8.28	7.97	8.12	8.25	7.83	8.14	8.02	7.44	7.85
EC	μS/cm	693	666	815	693	662	764	815	715	743	765	808	777	764
T	°C	13.4	12.2	15.3	13.9	14.2	12.6	10.1	10.1	11.56	12.0	11.7	11.0	16.4

Selected Parameters		Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent
		01/23/07	02/15/07	03/14/07	04/09/07	05/08/07	06/05/07	06/05/07	07/11/07	08/06/07	09/05/07	10/10/07	11/06/07	12/04/07
Fe (total)	mg/l	1.5	1.13	1.05	1.09	1.44	1.51	6.5	1.79	0.86	<0.1	<0.1	<0.1	<0.1
Mn (total)	mg/l	2.13	1.88	1.82	1.75	1.59	1.55	1.67	0.87	0.57	0.41	0.78	0.49	0.41
TSS	mg/l	6	6	12	9	6	4	12	6	10	2	4	1	6
pH		7.8	8.3	9.3	8.27	8.57	8.25	8.13	8.36	8.21	8.08	8.11	7.08	7.66
EC	μS/cm	743	650	683	647	639	730	786	685	761	817	433	858	764
T	°C	17.4	14.8	19.8	17.6	19.2	8.1	12.3	14.0	18.7	19.3	15.9	11.3	16.3

VLS-Vapor/Liquid Separator Sample Port

SYSTEM WATER QUALITY MONITORING

2008

VLS		VLS	VLS	VLS	VLS	VLS
		01/03/08	02/07/08	03/04/08	04/22/08	06/17/08
MTBE	ppb	1.0	1.3	1.7	1.6	<1
Benzene	ppb	11.8	5.2	5.7	11.6	<1
Toluene	ppb	62.1	44.7	58.7	62.9	<1
Ethyl Benzene	ppb	3.4	1.5	2.0	2.8	<1
Xylenes (Total)	ppb	90.0	56.2	59.0	77.0	<3
GRO (TPH)	mg/l	0.5	0.3	0.3	0.4	<0.2

Discharge		Effluent	Effluent	Effluent	Effluent	Effluent
		01/03/08	02/07/08	03/04/08	04/22/08	06/17/08
MTBE	ppb	<1	<1	<1	<1	<1
Benzene	ppb	<1	<1	<1	<1	<1
Toluene	ppb	<1	<1	<1	<1	<1
Ethyl Benzene	ppb	<1	<1	<1	<1	<1
Xylenes (Total)	ppb	<3	<3	<3	<3	<3
Phenols (Total)	ppb	10.1	<10	<10	<10	21.4
GRO (TPH)	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2

WATER QUALITY MONITORING

Selected Parameters		VLS	VLS	VLS	VLS	VLS
		01/03/08	02/07/08	03/04/08	04/22/08	06/17/08
pH		7.69	7.8	6.14	6.89	6.69
EC	µS/cm	772	722	759	825	1149
T	°C	12.8	10.7	9.4	9.0	13.3

Selected Parameters		Effluent	Effluent	Effluent	Effluent	Effluent
		01/03/08	02/07/08	03/04/08	04/22/08	06/17/08
Fe (total)	mg/l	<0.1	<0.1	<0.1	<0.1	0.29
Mn (total)	mg/l	0.42	0.34	0.36	0.3	1.75
TSS	mg/l	3	<3	1	2	1
pH		8.24	7.52	7.15	7.42	7.22
EC	µS/cm	739	779	719	710	1114
T	°C	18.1	16.3	14.0	14.1	24.7

VLS-Vapor/Liquid Separator Sample Port

APPENDIX C-2

OFFGAS QUALITY

OFFGAS QUALITY MONITORING

Organic Vapors By Charcoal Tube Desorption, Summit Analyzer, Flame Ionization Detector, and Photo Ionization Detector
Data represent combined VOC concentrations for extraction wellfield MPE- 1,4,5 and SVE 1,2,4,5

Date/Time	Collection Interval	Sampling Flow Rate (L/min)	GRO (mg/m^3)	TPH (mg/m^3)	MTBE (mg/m^3)	Benzene (mg/m^3)	Toluene (mg/m^3)	Ethyl benzene (mg/m^3)	Xylenes (mg/m^3)	Summit (ppm)	FID (ppm)	PID (ppm)	O_2 (%)	CO_2 (%)
8/31/06 15:46	[1]CT-60 s	0.28	5570	6420	ND	28	71	211	272	3365	NM	NM	16.4	0.05
8/31/06 15:48	[1]CT-60 s	0.28	7770	8510	ND	41	106	21	387	1926	NM	8.23		
9/19/06 14:30	[1]CT-60 s	0.28	7090	18400	ND	69	89	ND	39	5353	OL	1856	17.7	0.05
9/20/06 13:30	[1]CT-60 s	0.28	7200	18300	ND	78	103	ND	45	4079	45017	1370		
9/27/06 8:00	[1]CT-60 s	0.28	18800	34500	ND	148	271	40	301	NM	32545	1431	17.65	0.05
9/27/06 8:00	[1]CT-60 s	0.28	16500	32200	ND	140	250	33	260					
10/4/06 10:13	[1]CT-60 s	0.28	5260	8980	ND	101	192	ND	87	2,400	6680	1410	19.25	0.02
10/4/06 10:15	[1]CT-60 s	0.28	6180	10400	ND	112	196	ND	100					
10/11/06 10:00	[1]CT-60 s	0.28	6990	10800	ND	123	234	ND	123	2,292	4504	1358	18.9	0.02
10/11/06 10:00	[1]CT-60 s	0.28	5710	9570	ND	113	195	ND	70					
10/18/06 10:10	[1]CT-60 s	0.28	4530	6820	ND	95	158	ND	58	1,802	5915	1231	19.85	0.02
10/18/06 10:10	[1]CT-60 s	0.28	4960	7300	ND	94	178	ND	69					
10/24/06 10:00	[1]CT-60 s	0.28	6680	9090	ND	121	277	27	141	1,853	5585	1198	19.52	0.02
10/24/06 10:00	[1]CT-60 s	0.28	5260	7290	ND	116	228	21	114					
11/1/06 9:20	[1]CT-60 s	0.28	10900	14400	ND	181	388	40	203	2425	9680	1510	20.03	0.02
11/1/06 9:20	[1]CT-60 s	0.28	9600	12600	ND	166	406	54	286					
11/8/2006 9:40	[1]CT-60 s	0.28	9290	12000	ND	155	361	42	238	2340	7690	1549	22.06	0.03
11/8/2006 9:40	[1]CT-60 s	0.28	9110	11700	ND	154	359	44	253					
11/22/06 10:00	[1]CT-60 s	0.28	8910	10800	ND	160	675	53	306	1650	5215	1263	19.72	0.01
12/20/06 9:30	[1]CT-60 s	0.28	4170	5250	ND	95	221	28	168	1139	2589	918	20.01	0.01
12/20/06 9:30	[1]CT-60 s	1.28	4150	5330	ND	89	216	28	170					

OFFGAS QUALITY MONITORING

Organic Vapors By Charcoal Tube Desorption, Summit Analyzer, Flame Ionization Detector, and Photo Ionization Detector
Data represent combined VOC concentrations for extraction wellfield MPE- 4 and SVE 1,2,4,5

Date/Time	Collection Interval	Sampling Flow Rate (L/min)	GRO (mg/m^3)	TPH (mg/m^3)	MTBE (mg/m^3)	Benzene (mg/m^3)	Toluene (mg/m^3)	Ethyl benzene (mg/m^3)	Xylenes (mg/m^3)	Summit (ppm)	FID (ppm)	PID (ppm)	O_2 (%)	CO_2 (%)
1/23/07 10:00	[1]CT-60 s	0.28	4970	6060	ND	113	292	35	222	1,071	2465	899	20.14	0.01
1/23/07 10:05	[1]CT-60 s	0.28	5250	6380	ND	113	300	41	270					
02/15/07 11:20	[1]CT-60 s	0.28	ND	172	ND	ND	ND	ND	ND	738	1572	720	20.44	0.01
02/15/07 11:25	[1]CT-60 s	0.28	3430	3890	ND	78	222	18	125					
03/14/07 11:00	[1]CT-60 s	0.28	3540	4230	ND	59	216	24	175	598	1281	901	22.1	0.01
03/14/07 11:10	[1]CT-60 s	0.28	3380	4020	ND	63	221	23	178					
4/10/07 16:00	[1]CT-60 s	0.28	3280	3870	ND	52	227	26	183	748	1350	644	20.36	0.01
4/10/07 16:05	[1]CT-60 s	0.28	3460	4120	ND	55	249	30	208					
5/8/07 14:00	[1]CT-60 s	0.28	2950	3580	ND	43	219	26	176	512	862.9	457	19	0
5/8/07 14:05	[1]CT-60 s	0.28	2970	3550	ND	42	226	25	179					
6/5/07 10:50	[1]CT-60 s	0.28	3080	3930	ND	64	255	31	192	847	1805	837	18.77	0.01
6/5/07 10:53	[1]CT-60 s	0.28	3440	4360	ND	63	277	33	209					
7/11/07 10:05	[1]CT-60 s	0.28	1500	1630	ND	25	198	19	130	378	943	467	20.24	0.01
7/11/07 10:10	[1]CT-60 s	0.28	1930	2120	ND	27	237	25	176					
8/6/07 16:50	[1]CT-60 s	0.28	2930	3230	ND	29	85	23	142	420	591.7	574	20.6	0
8/6/07 16:55	[1]CT-60 s	0.28	3060	3350	ND	31	94	21	88					
9/5/07 10:45	[1]CT-60 s	0.28	1890	2040	ND	10	34	21	150	223	301.3	336	20.58	0
9/5/07 10:50	[1]CT-60 s	0.28	1860	2060	ND	9.3	31	21	145					
10/10/07 13:35	[1]CT-60 s	0.28	1450	1690	ND	37	82	ND	98	221	331	273	20.5	0
10/10/07 13:40	[1]CT-60 s	0.28	1560	1780	ND	39	95	ND	105					

OFFGAS QUALITY MONITORING

Organic Vapors By Charcoal Tube Desorption, Summit Analyzer, Flame Ionization Detector, and Photo Ionization Detector
Data represent combined VOC concentrations for extraction wellfield MPE-1 and 4 and SVE 1,2,4,5

Date/Time	Collection Interval	Sampling Flow Rate (L/min)	GRO (mg/m^3)	TPH (mg/m^3)	MTBE (mg/m^3)	Benzene (mg/m^3)	Toluene (mg/m^3)	Ethyl benzene (mg/m^3)	Xylenes (mg/m^3)	Summit (ppm)	FID (ppm)	PID (ppm)	O_2 (%)	CO_2 (%)
11/6/07 10:10	[1]CT-60 s	0.28	746	914	ND	ND	29	ND	50	69	130.5	206	21.1	0
11/6/07 10:15	[1]CT-60 s	0.28	671	857	ND	ND	31	ND	54					
12/04/07 11:10	[1]CT-60 s	0.28	479	675	ND	ND	31	ND	41	54	146.7	129	19.7	0
12/04/07 11:15	[1]CT-60 s	0.28	461	643	ND	ND	33	ND	45					
01/03/08 09:10	[1]CT-60 s	0.28	382	536	ND	ND	24	ND	32	44	110.4	64.3	19.8	0
01/03/08 09:15	[1]CT-60 s	0.28	425	586	ND	ND	29	ND	41					
02/07/08 11:30	[1]CT-60 s	0.28	334	464	ND	ND	24	ND	22	144	62.9	70.3	20.4	0
02/07/08 11:40	[1]CT-60 s	0.28	352	457	ND	ND	24	ND	27					
03/03/08 09:10	[1]CT-60 s	0.28	375	493	ND	ND	29	ND	25	74	65.7	82.3	19.8	0
03/03/08 09:15	[1]CT-60 s	0.28	389	511	ND	ND	34	ND	30					
04/22/08 10:50	[1]CT-60 s	0.28	316	507	ND	ND	25	ND	ND	83	119.5	89.3	20.47	0
04/22/08 10:55	[1]CT-60 s	0.28	361	579	ND	ND	28	ND	ND					
06/17/08 10:00	[1]CT-60 s	0.28	ND	ND	ND	ND	ND	ND	ND	33	9.2	31.2	22.4	0
06/17/08 10:08	[1]CT-60 s	0.28	ND	ND	ND	ND	ND	ND	ND					
07/14/08 16:35	[1]CT-60 s	0.28	ND	ND	ND	ND	ND	ND	ND					
07/14/08 16:40	[1]CT-60 s	0.28	ND	ND	ND	ND	ND	ND	ND					

[1]Charcoal tube sample collected from tedlar bag

GRO - Gasoline Range Organics
TPH - Total Purgeable Hydrocarbons
CT - Charcoal Tube

FID - Flame Ionization Detector
PID - Photoionization Detector
Summit - Summit HydrocarbonAnalyzer

ND - Not Detected
NM - Not Measured
OL=Overloaded
>10,000 ppmv for Summit (calibrated on hexane)
>10,000 ppmv for PID (calibrated on isobuthylene)
>50,000 ppmv for FID (calibrated on methane)

APPENDIX C-3

HYDRAULIC RESPONSE – WATER-TABLE MONITORING

Groundwater Levels

Elevations in feet

Well ID	MP (TOC)[1]	Ground	08/23/06	09/19/06	09/20/06	10/04/06	10/24/06	11/01/06	11/22/06	12/20/06	01/23/07	02/14/07	03/14/07	04/10/07	05/08/07
Extraction Wells															
MPE-1	1570.69	1571.14	1543.73	1544.06	1540.31	1543.28	1540.66	1543.73	1544.50	1544.48	1543.58	1544.57	1544.26	1545.36	1544.68
MPE-2	1570.86	1569.55	1543.90	1544.08	1543.56	1543.45	1544.50	1543.93	1544.57	1544.50	1543.77	1544.57	1544.28	1545.33	1544.69
MPE-3	1571.49	1571.74	1543.58	1543.77	1542.87	1542.84	1544.01	1543.19	1544.05	1544.32	1543.30	1544.39	1544.10	1545.11	1544.54
MPE-4	1571.60	1571.97	1543.63	1543.80	1540.36	1540.25	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60
MPE-5	1571.61	1571.88	1543.46	1543.76	1540.27	1540.23	1544.51	1539.84	1541.80	1544.32	1543.27	1544.40	1544.11	1545.20	1544.54
Monitoring Wells															
MW-2	1571.06	1571.24	1543.81	1544.39	1543.83	1543.72	1544.71	1544.17	1544.76	1544.61	1543.90	1544.68	1544.46	1545.47	1544.85
MW-6	1573.66	1571.31	1543.77	1544.24	1544.25	1543.66	1544.71	1544.19	1544.68	1544.58	1544.11	1544.61	1544.43	1545.47	1544.80
MW-7	1572.42	1569.99	1543.84	1544.22	1544.22	1543.74	1544.57	1544.24	1544.54	1544.43	1544.15	1544.53	1544.31	1545.32	1544.62
MW-9	1573.28	1571.52	1542.52	1543.69	1542.59	1542.35	1544.66	1543.03	1544.74	1544.58	1542.77	1544.64	1544.38	1545.44	1544.81
MW-10	1573.71	1571.76	1543.60	1543.70	1543.37	1543.40	1544.43	1543.90	1544.55	1544.49	1543.62	1544.54	1544.28	1545.33	1544.68
MW-11	1570.91	1571.27	1543.95	1544.11	1543.58	1543.60	1544.53	1543.98	1544.59	1544.52	1543.76	1544.60	1544.28	1570.91	1544.75
MW-12	1573.22	1571.58	1543.63	1543.87	1543.12	1543.39	1544.19	1543.88	1543.55	1544.50	1543.63	1544.56	1544.29	1545.35	1544.71
Injection/Sparge Wells															
IW-1	1571.27	1571.88	1543.65		1543.04	1542.95	1544.30	1543.36	1544.33	1544.33	1543.20	1544.39	1544.10	1545.16	1544.51
IW-2	1571.61	1572.09	1543.63		1542.98	1542.91	1544.28	1543.32	1544.31	1544.31	1543.17	1544.39	1544.09	1545.15	1544.51
IW-3	1571.62	1572.08	1543.66		1543.02	1542.92	1544.26	1543.37	1544.28	1544.27	1543.10	1544.32	1544.08	1545.16	1544.44
IW-4	1571.68	1572.11	1543.85		1543.83	1543.84	1543.86	1544.08	1544.09	1544.08	1544.07	1543.94	1542.87	1544.82	1544.57
IW-5	1571.67	1572.13	1543.58		1542.82	1542.74	1544.24	1544.15	1544.27	1544.24	1543.17	1544.32	1544.02	1545.09	1544.47

[1]MP (TOC) - measuring point after wellhead instrumentation or top of casing

4/22/2008 MPE System shutdown and startup of ozone sparging

8/12/2008 Municipal well operated at 800 gpm

nm Not measured - wellhead flooded or inaccessible

Groundwater Levels

Elevations in feet

Well ID	MP (TOC)[1]	Ground	06/05/07	07/11/07	08/06/07	09/05/07	10/09/07	11/06/07	12/04/07	01/03/08	02/07/08	03/04/08	04/23/08	06/12/08	07/14/08
Extraction Wells															
MPE-1	1570.69	1571.14	1545.01	1540.18	1537.70	1537.70	1537.70	1537.70	1537.70	1537.70	1537.70	1537.70	1544.20	1543.96	1544.50
MPE-2	1570.86	1569.55	1545.02	1544.38	1544.38	1544.36	1544.17	1544.99	1545.08	1545.14	1544.56	1544.51	1544.51	1544.00	1544.29
MPE-3	1571.49	1571.74	1544.86	1545.92	1545.65	1544.12	1543.85	1545.23	1545.19	1545.34	1544.23	1544.21	1544.22	1541.44	1544.53
MPE-4	1571.60	1571.97	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1537.60	1544.42	1544.18	1537.60
MPE-5	1571.61	1571.88	1544.85	1548.93	1548.91	1545.91	1544.03	1548.31	1548.69	1548.30	1546.35	1544.85	1544.45	1547.36	1543.38
Monitoring Wells															
MW-2	1571.06	1571.24	1545.17	1544.55	1544.61	1544.69	1544.38	1545.12	1545.16	1545.26	1544.68	1544.60	1544.65	1543.95	1544.38
MW-6	1573.66	1571.31	1545.17	1544.48	1544.34	1544.67	1544.45	1545.15	1545.27	1545.30	1544.91	1544.93	1544.91	1544.19	1543.97
MW-7	1572.42	1569.99	1545.07	1544.41	1544.31	1544.66	1544.36	1545.04	1545.16	1545.13	1544.87	1544.87	1544.81	1544.16	1543.69
MW-9	1573.28	1571.52	1545.12	1543.52	1544.37	1543.75	1544.39	1545.13	1545.08	1545.30	1544.02	1544.11	1544.87	1543.50	1544.08
MW-10	1573.71	1571.76	1545.01	1544.58	1544.98	1544.36	1544.02	1544.91	1544.97	1545.07	1544.33	1544.20	1544.45	1544.01	1544.54
MW-11	1570.91	1571.27	1545.08	1544.43	1544.33	1544.40	1544.23	1545.00	1545.11	1545.17	1544.64	1544.67	1544.59	1544.08	1544.29
MW-12	1573.22	1571.58	1545.03	1544.41	1545.11	1545.42	1543.88	1545.59	1546.18	1547.55	1545.77	1546.55	1544.48	1544.96	1544.78
Injection/Sparge Wells															
IW-1	1571.27	1571.88	1544.85	Active	Active	Active	1544.14	Active	Active	Active	Active	Active	Active	Active	Active
IW-2	1571.61	1572.09	1544.85	Active	Active	Active	1544.12	Active	Active	Active	Active	Active	Active	Active	Active
IW-3	1571.62	1572.08	1544.77	Active	Active	Active	1544.09	Active	Active	Active	Active	Active	Active	Active	Active
IW-4	1571.68	1572.11	1544.34	Active	Active	Active	1544.08	Active	Active	Active	Active	Active	Active	Active	Active
IW-5	1571.67	1572.13	1544.78	Active	Active	Active	1544.06	Active	Active	Active	Active	Active	Active	Active	Active

[1]MP (TOC) - measuring point after wellhead instrumentation or top of casing

4/22/2008 MPE System shutdown and startup of ozone sparging

8/12/2008 Municipal well operated at 800 gpm

nm Not measured - wellhead flooded or inaccessible

Groundwater Levels

Elevations in feet

Well ID	MP (TOC)[1]	Ground	08/12/08	09/09/08	09/30/08	10/22/08	11/26/08	12/10/08
Extraction Wells								
MPE-1	1570.69	1571.14	1541.83	1548.28	1542.65	1541.44	nm	nm
MPE-2	1570.86	1569.55	1542.21	1542.52	1542.83	1542.63	nm	nm
MPE-3	1571.49	1571.74	1541.65	1540.10	1542.77	1540.59	1541.39	1541.40
MPE-4	1571.60	1571.97	1542.21	1544.00	1542.29	1541.21	1544.80	nm
MPE-5	1571.61	1571.88	1541.39	1545.55	1542.93	1544.61	1547.21	1545.96
Monitoring Wells								
MW-2	1571.06	1571.24	1542.29	1542.21	1543.14	1542.50	1542.81	nm
MW-6	1573.66	1571.31	1542.89	1544.42	1543.46	1543.86	1544.32	1544.50
MW-7	1572.42	1569.99	1543.10	1541.67	1543.36	1543.56	1543.88	1544.25
MW-9	1573.28	1571.52	1542.43	1542.58	1541.85	1542.94	1543.22	1543.74
MW-10	1573.71	1571.76	1542.07	1542.32	1542.81	1542.55	1543.20	1543.51
MW-11	1570.91	1571.27	1542.33	1542.58	1543.04	1541.75	nm	nm
MW-12	1573.22	1571.58	1541.98	1540.92	1542.82	1546.69	1544.46	1544.52
Injection/Sparge Wells								
IW-1	1571.27	1571.88	Active	Active	1542.58	Active	Active	Active
IW-2	1571.61	1572.09	Active	Active	1542.50	Active	Active	Active
IW-3	1571.62	1572.08	Active	Active	1542.21	Active	Active	Active
IW-4	1571.68	1572.11	Active	Active	1542.16	Active	Active	Active
IW-5	1571.67	1572.13	Active	Active	1542.07	Active	Active	Active

[1]MP (TOC) - measuring point after wellhead instrumentation or top of casing

4/22/2008 MPE System shutdown and startup of ozone sparging

8/12/2008 Municipal well operated at 800 gpm

nm Not measured - wellhead flooded or inaccessible

APPENDIX C-4

PNEUMATIC RESPONSE

Pneumatic Response - Vacuum Pressure Monitoring

Recorded by Dwyer FM-477 Manometer

Well ID	09/19/06 (in.H_2O)	09/19/06 (in.H_2O)	09/20/06 (in.H_2O)	10/04/06 (in.H_2O)	10/11/06 (in.H_2O)	10/18/06 (in.H_2O)	10/24/06 (in.H_2O)	11/01/06 (in.H_2O)	11/08/06 (in.H_2O)	11/22/06 (in.H_2O)	12/20/06 (in.H_2O)	01/23/07 (in.H_2O)	02/15/07 (in.H_2O)	03/14/07 (in.H_2O)
Extraction Wells														
MPE-1	0.0	-23.3	-24.3	-15.4	-10.9	-15.4	-22.1	-15.5	-11.4	-12.5	-10.5	-13.6	-7.2	-10.1
MPE-2	0.0	-9.2	-9.7	-10.5	-5.4	-10.4	-6.3	-9.8	-6.3	-7.3	-6.2	-8.9	-3.6	-6
MPE-3	0.0	-17.5	-19.5	-18.1	-14.1	-18.4	-15.2	-18.8	-14.4	-15.6	-12.2	-16.1	-9.9	-12.2
MPE-4	0.0	-116.6	-138.0	-153.6	-144.8	-164.5	-140.7	-175.7	-165.7	-175.8	-180.3	-191.4	-188.4	-195.9
MPE-5	0.0	-26.2	-26.4	-28.5	-25.9	-31.5	-27.1	-32.9	-29.1	-29.8	-10.9	-17.3	-9.7	-13.6
Soil Vapor Extraction Wells														
SVE-1	0.0	-215.2	-231.4	-225.4	-231.2	-247.2	-225.3	-30.7	ol	ol	ol	ol	-0.5	0
SVE-2	0.0	-232.6	-241.2	-188.5	-200.6	-226.3	-206.8	-248	ol	ol	ol	-1.6	0	-0.3
SVE-3	0.0	-6.1	-0.7	-0.8	-0.8	-1.1	-7.8	-13.6	-2.4	-0.3	0	0	-0.4	0
SVE-4	0.0	-205.7	-220.0	-229.6	-244.5	-249.4	-234.2	ol	ol	ol	ol	ol	ol	ol
SVE-5	0.0	-0.1	0.0	0.0	-0.1	-1.0	-0.9	1.3	0	0	0	0	0	0
SVE-6	0.0	-228.3	-216.7	-226.3	-238.2	-246.3	-224.7	-247.1	-199.6	-212.8	-208.7	-235.4	ol	ol
SVE-7	0.0	-159.3	-176.6	-206.3	-194.2	-156.5	-141.8	-173.2	-126.1	-128.6	-147.3	-162.3	-183.7	-200.6
Monitoring Wells														
MW-2	0.0	0	-11.3	-10.5	-6.3	-10.4	-6.6	-9.9	-6.7	-7.7	-6.5	-9.3	-3.8	-6.3
MW-10	0.0	-15.1	-15.1	-14.9	-10.6	-14.9	-11.9	-14.5	-11	-11.9	-10.7	-14.2	-7.6	-10.5
MW-11	0.0	-9.3	-9.8	-10.1	-7.2	-11.3	-7.6	-4.5	-6.8	-7.9	0	0	0	-6.3
MW-12	0.0	-17.5	-17.5	-15.6	-11.1	-15.6	-11.8	-10.2	-11.9	-12.7	-11.1	-14.4	-8.3	-10.8
Injection/Sparge Wells														
IW-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	0.0	0.0	0.0	0.0	0.0	0.0
IW-2	0.0	0.0	-1.4	-1.3	0.0	0.0	0.0	0.0	0.0	-1.3	0.0	-1.0	-0.9	-1.4
IW-3	0.0	0.0	-1.4	-1.1	0.0	-1.9	0.0	-2.1	-0.2	-1.1	0.0	-0.9	-0.8	-0.3
IW-4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	0.0	0.0	0.0	0.0
IW-5	0.0	0.0	0.0	0.0	0.0	-0.8	0.0	-1.1	0.0	-0.6	0.0	0.0	0.0	-0.1

Operational wells

ol - Over limit of Dwyer manometer

Pneumatic Response - Vacuum Pressure Monitoring

Recorded by Dwyer FM-477 Manometer

Well ID	04/10/07 (in.H_2O)	05/08/07 (in.H_2O)	06/05/07 (in.H_2O)	07/11/07 (in.H_2O)	08/06/07 (in.H_2O)	09/05/07 (in.H_2O)	10/07/07 (in.H_2O)	11/06/07 (in.H_2O)	12/04/07 (in.H_2O)	01/03/08 (in.H_2O)	02/07/08 (in.H_2O)	03/04/08 (in.H_2O)	04/22/08 (in.H_2O)	06/02/08 (in.H_2O)
Extraction Wells														
MPE-1	-9.1	-9.3	-8.6	-36.2	-36.2	-31.8	-58.1	-46.1	-41.7	-43.4	-50.8	-52.2	-51.2	NM
MPE-2	-5.2	-5.1	-4.7	-9.6	-5.1	+2.1	-10.4	+2.6	+6.4	+2.9	0	+0.1	+1.5	NM
MPE-3	-11.4	-10.8	-10.4	-9.9	-1.4	+10.4	-18.6	+13.2	+16.4	+12.8	+7.4	+5.3	+9.6	+32.7
MPE-4	-190.3	-204.8	-201.3	-195.4	-147.1	-157.3	-181.2	-162.8	-157.1	-159.2	-172.2	-174.5	-170.6	+22.1
MPE-5	-0.6	-9.1	-5.1	+38.5	+67.3	+49.4	-14.2	+53	+42.1	+33.4	+16.7	+16.5	+42.1	+53.1
Soil Vapor Extraction Wells														
SVE-1	-90.3	ol	ol	ol	-201.6	-178.7	-225.1	-213.4	-201.3	-220.4	0	0	-230.1	+3.5
SVE-2	-0.3	ol	-230.4	-203.5	-178.4	-151.1	-189.7	-189.3	-172.4	-153.4	0	0	-142.1	+1.3
SVE-3	0.1	0	-0.2	0	0	0	-1.9	-2.1	+.3	0	0	0	-0.1	+0.3
SVE-4	ol	ol	-230.5	-205.7	-161.4	-154.6	-189.9	-165.7	-157.4	-154.3	0	-138.4	-148.5	-1.3
SVE-5	0	0	0	0	0	0	-0.1	0	0	0	0	0	0	0
SVE-6	ol	ol	-229.1	-208.3	-182.8	-161.9	-205.7	-170.6	-158.1	-157.6	-174.4	-148.2	-154.7	+3.5
SVE-7	-189.7	-129.5	-143.7	-106.4	-94.3	-48.6	-105.3	-104.9	-73.8	-101	-54.5	-71.5	-107.5	-26.3
Monitoring Wells														
MW-2	-5.6	-5.4	-4.8	-9.9	-3.5	+6.2	-9.2	+5.2	+9.5	+5.2	+2	+1.3	+3.7	+22.3
MW-10	-9.2	-9.3	-8.5	-13.9	-8.2	+1.6	-17.3	+2.6	+6.4	+2.9	-1.4	-3	+1.4	+24.4
MW-11	-5.4	-7.4	-5.5	-9.4	-5.3	+2.3	-10.8	+8.9	0	+0.1	0	+0.5	+1.9	nm
MW-12	-9.7	-9.8	-9.2	-17.3	-10.9	-1.6	-22.3	-1.6	+2.4	-0.9	-5.5	-7.1	-2.7	+25.7
Injection/Sparge Wells														
IW-1	0.0	0.0	0.0	active	active	active	0.0	+223.7	+213.2	+217.0	+205.6	+203.	+217.8	+191.5
IW-2	-0.4	0.0	0.0	active	active	active	0.0	+217.4	+214.5	+216.8	+204.3	+203.7	+213.4	ol
IW-3	0.0	-0.1	0.0	active	active	active	0.0	+233.9	+230.1	+228.8	+215.3	+213.4	+228.6	+235.8
IW-4	0.0	-0.2	0.0	active	active	active	0.0	ol	+243.8	+240.9	+230.4	+226.3	+236.7	+205
IW-5	0.0	0.0	0.0	active	active	active	0.0	+202.4	+201.5	+202.6	+192.7	+189.2	+200.6	+214.7

Operational wells
ol - Over limit of Dwyer manometer
+ indicates positive pressure at well head (sparging system response).
nm - not measured during 3-day monitoring for municipal well

Pneumatic Response - Vacuum Pressure Monitoring

Recorded by Dwyer FM-477 Manometer

Well ID	06/12/08 ($in.H_2O$)	06/17/08 ($in.H_2O$)	07/14/08 ($in.H_2O$)	08/12/08 ($in.H_2O$)	09/09/08 ($in.H_2O$)	09/30/08 ($in.H_2O$)	10/20/08 ($in.H_2O$)	10/22/08 ($in.H_2O$)	11/26/08 ($in.H_2O$)	12/10/08 ($in.H_2O$)
Extraction Wells										
MPE-1	+22.9	+10.9	-2.2	+0.4	+20.7	-0.3	nm	+20.9	nm	nm
MPE-2	+18.7	+8.9	0	0	+14.9	0	nm	+15.1	nm	nm
MPE-3	+32.6	+14.9	-1.3	+1.1	+26.2	+10.3	+26.1	+26.8	+33.8	+32.8
MPE-4	+24.3	-164.5	-151.4	+0.1	+17.1	-0.7	+20.6	+21.6	+26.8	+26.9
MPE-5	+50.7	+55.3	+25.3	+2.4	+54.8	+4.6	+39.4	+45.4	+43.0	+49.5
Soil Vapor Extraction Wells										
SVE-1	+2.7	+0.1	0	0	+2.2	0	nm	nm	0	0
SVE-2	+0.3	-0.7	0	0	0	-3.5	nm	nm	-3.9	+3.2
SVE-3	-0.1	0	0	0	0	-3.5	nm	nm	-0.3	-0.1
SVE-4	-1.4	0	0	0	+.9	-4.2	nm	nm	-3.4	-1.4
SVE-5	0	0	0	0	-3.9	0	nm	nm	0	0
SVE-6	+3.4	0	0	0	+.5	0	nm	nm	+0.8	-0.4
SVE-7	-15.6	0	0	0	0	0	nm	nm	0	0
Monitoring Wells										
MW-2	+20.4	+17.6	+1.3	+0.1	+15.7	0	nm	+15.1	+19.5	NM
MW-10	+23.6	+9.4	-2.9	+0.4	+17.8	+0.5	nm	+19.3	+23.0	+25.6
MW-11	+18.6	+10.0	0	-0.7	+15.1	+0.4	nm	+15.2	NM	NM
MW-12	+25.1	+10.3	-2.9	+0.5	+20.1	+0.5	nm	+20.9	+25.0	+27.5
Injection/Sparge Wells										
IW-1	+209.8	+221.8	+205.1	+153.9	+195.2	-0.4	nm	nm	+198.5	+187.3
IW-2	+200.3	+208.5	+199.1	+162.7	+182.9	-0.7	nm	nm	+199.7	+193.2
IW-3	+230.2	+242.9	+217.9	+165.9	+224.4	0.0	nm	nm	+206.5	+204.7
IW-4	ol	ol	ol	+172	ol	0.0	nm	nm	ol	+232.5
IW-5	+185.6	+196.9	+185.3	+154.2	+167.3	+21.8	nm	nm	+190.5	+187.5

Operational wells
OL - Over limit of Dwyer manometer
+ indicates positive pressure at well head (sparging system response).
nm - not measured during 3-day monitoring for municipal well

APPENDIX D

MASS BALANCE WORKSHEETS

CONTAMINANT RECOVERY

TPH - Vapor Phase

Date	Runtime (cum. h)	Q_{air} (scfm)	Volume (1000 ft^3)	TPH_{air} [1] (mg/m^3)	$BTEX_{air}$ [1] (mg/m^3)	TPH_{mass} (lb)	$BTEX_{mass}$ (lb)
09/20/06	52.5	39.7	125	18,350	211.5	100.6	3.0
09/27/06	147.8	87.2	499	33,350	721.5	804.6	14.5
10/04/06	318.1	95.4	975	9,690	394.0	1309.2	33.9
10/11/06	485.8	88.5	891	10,185	429.0	552.6	22.9
10/18/06	652.1	85.3	851	7,060	326.0	458.0	20.1
10/24/06	795.9	85.3	736	8,190	522.5	350.4	19.5
11/01/06	983.7	60.0	961	13,500	862.0	650.8	41.5
11/08/06	1152.1	50.6	606	11,850	803.0	479.5	31.5
11/22/06	1486.3	57.5	1,015	10,800	1194.0	717.4	63.3
12/20/06	2133.1	63.4	2,231	5,290	507.5	1120.6	118.5
01/23/07	2951.1	55.1	3,112	6,220	693.0	1117.9	116.6
02/15/07	3502.0	47.8	1,821	3,890	443.0	574.7	64.6
03/14/07	4150.2	52.6	1,859	4,125	479.5	465.1	53.5
04/10/07	4801.7	42.0	2,056	3,995	515.0	521.1	63.8
05/08/07	5471.1	45.1	1,687	3,565	468.0	398.1	51.8
06/05/07	6139.3	45.5	1,808	4,145	562.0	435.1	58.1
06/05/07	6144.5	50.9	14	3,380	414.5	3.4	0.4
07/11/07	6969.6	47.5	2,520	1,875	418.5	413.3	65.5
08/06/07	7535.2	59.8	1,612	3,290	256.5	259.9	34.0
09/05/07	8232.1	84.8	2,501	2,050	210.7	416.8	36.5
10/10/07	9045.0	50.6	4,136	1,735	228.0	488.7	56.6
11/06/07	9688.5	80.4	1,954	886	82.0	159.8	18.9
12/04/07	10360.7	86.3	3,243	659	75.0	156.3	15.9
01/03/08	11079.2	87.7	3,720	561	63.0	141.7	16.0
02/07/08	11920.5	81.4	4,427	461	48.5	141.2	15.4
03/03/08	12496.2	81.5	2,812	502	59.0	84.5	9.4
04/22/08	13668.2	94.0	5,731	543	0.0	186.9	15.3
05/13/08	14169.8	94.0	2,829	543	0.0	95.9	4.7
06/17/08	14970.3	52.1	4,515	0	0.0	0.0	0.0
Total			**61,245**			**12,604**	**1,066**

CONTAMINANT RECOVERY

TPH - Liquid Phase

Date	Totalizer (gal)	Flow (gpm)	TPH_{water} mg/l	$BTEX_{water}$ mg/l	TPH_{mass} (lb)	$BTEX_{mass}$ (lb)
	Recovery Field 1					
09/20/06	25546	8.7	5.68	1.9	1.4	0.481
09/27/06	74546	8.1	6.43	2.3	2.5	0.857
10/04/06	119526	4.5	4.31	1.7	2.0	0.750
10/11/06	159474	3.9	5.15	1.9	1.6	0.608
10/18/06	212840	5.4	4.62	1.9	2.2	0.853
10/24/06	258237	5.1	4.57	2.1	1.7	0.768
11/01/06	330492	6.5	5.41	2.3	3.0	1.344
11/08/06	394162	6.3	5.19	2.4	2.8	1.243
11/22/06	518608	6.2	4.66	2.1	5.1	2.322
12/20/06	640010	3.1	4.03	2.0	4.4	2.091
01/23/07	679355	0.8	4.32	1.9	1.4	0.649
02/15/07	708015	0.9	3.42	1.4	0.9	0.404
03/14/07	736088	0.7	2.44	1.0	0.7	0.284
04/10/07	766010	0.8	2.51	1.1	0.6	0.255
05/08/07	800556	0.9	2.10	0.9	0.7	0.281
06/05/07	828424	0.7	2.99	1.4	0.6	0.262
06/05/07	829058	2.0	2.54	0.9	0.0	0.006
07/11/07	1122345	5.9	2.70	1.2	6.4	2.587
08/06/07	1230818	3.2	2.64	0.9	2.4	0.928
09/05/07	1366053	3.2	2.14	0.8	2.7	0.959
10/10/07	1507091	2.9	1.00	0.4	1.8	0.750
11/06/07	1623252	3.0	0.88	0.2	0.9	0.322
12/04/07	1742083	2.9	0.76	0.2	0.8	0.202
01/03/08	1869043	2.9	0.53	0.2	0.7	0.189
02/07/08	2021284	3.0	0.34	0.1	0.6	0.175
03/03/08	2132290	3.2	0.35	0.1	0.3	0.108
04/22/08	2328610	2.8	0.40	0.2	0.6	0.229
05/13/08	2416582	3.1	0.40	0.2	0.3	0.113
06/17/08	2425516	0.2	0.00	0.0	0.0	0.006
Total					**49.2**	**20.0**

SPARGING OXIDANT DELIVERY AND DEGRADATION ESTIMATE

Date	Runtime (h)	Q_{air} (scfm)	$Volume_{air}$ (1000 ft^3)	$Volume_{oxygen}$ (1000 ft^3)	Mass[1] $_{oxygen}$ (kg)	Degradation (kg)
07/11/07	10.5	49.0	28	5.9	4.7	1.5
08/06/07	554.0	58.7	1952	409.9	331.0	105.9
09/05/07	710.5	39.3	1674	351.4	283.8	90.8
10/10/07	829.5	59.3	2953	620.1	500.8	160.2
11/06/07	656.5	56.7	2234	469.1	378.9	121.2
12/04/07	684.0	55.8	2292	481.2	388.6	124.4
01/03/08	731.0	53.5	2346	492.6	397.9	127.3
02/07/08	857.5	51.4	2646	555.7	448.8	143.6
03/04/08	633.5	52.5	1996	419.1	338.5	108.3
04/22/08	1172.0	49.2	3457	726.0	586.3	187.6
05/13/08	481.0	47.9	1383	290.4	234.5	75.0
06/17/08	746.0	54.9	2457	515.9	416.6	133.3
07/14/08	614.5	43.2	1592	334.3	270.0	86.4
08/12/08	577.9	33.7	1169	245.5	198.3	63.5
09/09/08	643.6	46.4	1790	375.9	303.6	97.1
10/01/08	491.0	51.3	1512	317.6	256.5	82.1
10/20/08	438.3	53.0	1395	292.9	236.6	75.7
11/26/08	906.1	50.4	2739	575.2	464.6	148.7
12/10/08	436.9	52.0	1363	286.1	231.1	73.9
Total	12174.4		36975	7764.8	6270.9	2006.7

[1]Asumptions: 21% in air, 2% transfer efficiency (Kuo, 1999)

APPENDIX E

GROUNDWATER QUALITY MONITORING – SUMMARY OF DATA

APPENDIX E-1

COC IN GROUNDWATER

GROUNDWATER QUALITY MONITORING
BTEX/GRO

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX mg/l
Extraction Wells								
MPE-1	08/23/06	<10	129.4	37.3	115	270.6	4.038	552
MPE-1	04/11/07	<10	153.3	<10	136.1	104.6	3.315	394
MPE-1	04/23/08	<1	<1	<1	<1	<3	<0.2	0
MPE-1	05/28/08	<1	<1	<1	<1	<3	<0.2	0
MPE-1	09/30/08	<1	<1	<1	<1	<3	<0.2	0
MPE-2	08/23/06	<1	2.8	<1	<1	<3	<0.2	3
MPE-2	04/11/07	<1	1.4	1.3	<1	<3	<0.2	3
MPE-2	10/09/07	<1	<1	<1	<1	<1	<0.2	0
MPE-2	04/22/08	<1	<1	<1	<1	<1	<0.2	0
MPE-2	09/30/08	<1	<1	<1	<1	<1	<0.2	0
MPE-3	08/23/06	<100	108.2	265	<100	324.2	<20	697
MPE-3	04/11/07	<1	<1	3.1	<1	<3	<0.2	3
MPE-3	10/10/07	<1	<1	<1	<1	<1	<0.2	0
MPE-3	04/23/08	<1	<1	<1	<1	<1	<0.2	0
MPE-3	09/30/08	<1	<1	<1	<1	<1	<0.2	0
MPE-4	08/23/06	<1	<1	<1	<1	<3	0.385	0
MPE-4	04/23/08	<1	<1	1.3	1.3	18.1	0.266	21
MPE-4	05/28/08	<1	1.7	<1	3.2	5.2	0.84	10
MPE-4	09/30/08	<1	1.2	2.3	<1	<3	0.291	4
MPE-5	08/23/06	<1	<1	<1	<1	<3	0.6	0
MPE-5	04/11/07	<1	1.9	<1	<1	<3	<0.2	2
MPE-5	10/10/07	<1	<1	<1	<1	<1	<0.2	0
MPE-5	04/23/08	<1	<1	<1	<1	<1	<0.2	0
MPE-5	09/30/08	<1	<1	<1	<1	<1	<0.2	0

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX mg/l
Monitoring Wells								
MW-2	08/23/06	<0.5	<0.4	<0.5	<0.4	<0.6	NA	0
MW-2	04/11/07	<1	<1	<1	<1	<3	<0.2	0
MW-2	10/09/07	<1	<1	<1	<1	<3	<0.2	0
MW-2	04/22/08	<1	<1	<1	<1	<3	<0.2	0
MW-2	10/01/08	<1	<1	<1	<1	<3	<0.2	0
MW-6	08/23/06	<0.5	1	<0.5	<0.4	<0.6	NA	1
MW-6	04/11/07	<1	7.6	1.2	<1	<3	<0.2	9
MW-6	10/10/07	<1	<1	<1	<1	<3	<0.2	0
MW-6	04/22/08	1.4	2.6	<1	<1	<3	<0.2	3
MW-6	10/01/08	1.8	1.1	<1	<1	<3	<0.2	1
MW-7	08/23/06	<0.5	<0.4	<0.5	<0.4	<0.6	NA	0
MW-7	04/11/07	<1	<1	<1	<1	<3	<0.2	0
MW-7	10/10/07	<1	<1	<1	<1	<3	<0.2	0
MW-7	04/22/08	<1	<1	<1	<1	<3	<0.2	0
MW-7	10/01/08	<1	<1	<1	<1	<3	<0.2	0
MW-9	08/23/06	<0.5	<0.4	<0.5	<0.4	<0.6	NA	0
MW-9	04/11/07	<1	<1	<1	<1	<3	<0.2	0
MW-9	10/09/07	<1	<1	<1	<1	<3	<0.2	0
MW-9	04/22/08	<1	<1	<1	<1	<3	<0.2	0
MW-9	10/01/08	<1	<1	<1	<1	<3	<0.2	0
MW-10	08/23/06	7.4	55.2	<2.5	57.6	<3	NA	113
MW-10	04/11/07	4.2	6.4	<1	4.3	<3	0.463	11
MW-10	10/09/07	3.5	<1	<1	<1	<3	<0.2	0
MW-10	04/23/08	7.7	2	1.6	<1	<3	<0.2	4
MW-10	10/01/08	<1	<1	<1	<1	<3	<0.2	0
MW-11	08/23/06	34.2	297.8	<5	160.1	<6	NA	458
MW-11	05/08/07	7.1	8.3	<1	2.3	<3	0.2	11
MW-11	10/09/07	<1	<1	<1	<1	<3	<0.2	0
MW-11	04/22/08	<1	<1	<1	<1	<3	<0.2	0
MW-11	09/30/08	<1	<1	<1	<1	<3	<0.2	0
MW-12	08/23/06	4.8	15.5	1.2	1.5	1.4	NA	20
MW-12	04/11/07	1.4	5.1	<1	<1	<3	<0.2	5
MW-12	10/09/07	<1	<1	<1	<1	<3	<0.2	0
MW-12	10/09/07	<1	<1	<1	<1	<3	<0.2	0
MW-12	04/23/08	<1	<1	<1	<1	<3	<0.3	0
MW-12	10/01/08	<1	<1	<1	<1	<3	<0.3	0

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX mg/l
Injection/Sparge Wells								
IW-1	08/23/06	<1	<1	<1	<1	3.1	0.451	3
IW-1	04/11/07	<1	1.8	11.4	1.3	9.8	0.657	24
IW-1	10/09/07	<1	<1	<1	<1	<3	<0.2	0
IW-1	04/23/08	<1	<1	<1	<1	<3	<0.2	0
IW-1	05/28/08	<1	<1	<1	<1	<3	<0.2	0
IW-1	09/30/08	<1	<1	<1	<1	<3	<0.2	0
IW-2	08/23/06	<1	1.8	<1	<1	<3	<0.2	2
IW-2	04/11/07	<1	<1	<1	<1	<3	0.597	0
IW-2	10/09/07	<1	<1	<1	<1	<3	<0.2	0
IW-2	04/23/08	<1	<1	<1	<1	<3	<0.2	0
IW-2	05/28/08	<1	<1	<1	<1	<3	<0.2	0
IW-2	09/30/08	<1	<1	<1	<1	<3	<0.2	0
IW-3	08/23/06	19.3	2585	75.8	57.2	77.8	5.71	2,796
IW-3	04/11/07	<10	1688	<10	25.6	<30	3.61	1,714
IW-3	10/09/07	<1	3.9	<1	<1	<3	<0.2	4
IW-3	04/23/08	<1	<1	<1	<1	<3	<0.2	0
IW-3	05/28/08	<1	1.7	<1	<1	<3	<0.2	2
IW-3	09/30/08	<1	<1	<1	<1	<3	<0.2	0
IW-4	08/23/06	<20	4880	819.7	475.7	1619	17.4	7,794
IW-4	04/11/07	<20	4122	<20	349.8	363.1	11.97	4,835
IW-4	10/09/07	<1	178	<1	<1	<3	0.329	178
IW-4	04/23/08	<1	34	<1	<1	<3	<0.2	34
IW-4	05/28/08	<1	33	<1	<1	<3	<0.2	33
IW-4	09/30/08	<1	7	<1	<1	<3	<0.2	7
IW-5	08/23/06	<20	4137	1005	762.9	1597	16.36	7,502
IW-5	04/11/07	<20	2403	<20	49.5	<60	5.34	2,453
IW-5	10/09/07	1.2	775	<1	1.9	<3	1.35	777
IW-5	04/23/08	<1	251	<1	<1	<3	0.49	251
IW-5	05/28/08	1.2	254	<1	1	<3	0.52	255
IW-5	09/30/08	<1	242	<1	<1	<3	0.44	242
Soil Vapor Extraction Wells								
SVE-1	08/23/06	Dry						
SVE-1	10/01/08	<50	2186	3397	511.1	5594	26.8	11,688
SVE-2	08/23/06	<100	32810	48320	2353	12460	148.9	95,943
SVE-2	10/01/08	<500	7262	13530	1201	7780	57.8	29,773
SVE-3	08/23/06	<10	85	198.7	17.4	88	48.12	389
SVE-3	10/02/08	<1	<1	<1	<1	<3	<0.2	0
SVE-4	08/23/06	Dry						
SVE-4	10/02/08	<5	37.7	18.2	868.1	1479	15.5	2,403
SVE-5	08/23/06	<50	<50	131.7	1027	4844	21.99	6,003
SVE-5	10/02/08	<1	<1	<1	<1	<3	<0.2	0
SVE-6	08/23/06	Dry						
SVE-6	10/02/08	<10	21.2	218.9	155.6	733	9.17	1,129
SVE-7	08/23/06	Dry						
SVE-7	10/02/08	<10	<10	11.7	105.4	298.6	5.235	416

Municipal Well

Date/Time	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	Laboratory
4/9/08 14:35	<2	<1	<1	<1	<1		MVTL[1]
							MVTL
7/15/08 8:45	<1	<1	<1	<3	<2	<0.2	MVTL
7/15/08 9:45	<1	<1	<1	<3	<2	<0.2	MVTL
7/15/08 12:15	<1	<1	<1	<3	<2	<0.2	MVTL
7/14/08 14:15	<1	<1	<1	<3	<2	<0.2	MVTL
7/15/08 12:15		ND	ND	ND	ND		NDDH
7/15/08 12:15		ND	ND	ND	ND		NDDH
8/12/08 12:00	<1	<1	<1	<3	<2	<0.2	MVTL
8/12/08 13:00	<1	<1	<1	<3	<2	<0.2	MVTL
8/12/08 14:00	1	3.4	27.4	2.3	4.4	<0.2	MVTL
8/12/08 11:30		ND	ND	ND	ND		NDDH
8/12/08 12:00		ND	ND	ND	ND		NDDH
9/9/08 8:45	<2	<1	<1	<1	<1		MVTL[1]
9/9/08 10:30	<2	<1	<1	<1	<1		MVTL[1]
9/9/08 12:30	<2	<1	<1	<1	<1		MVTL[1]
10/20/08 14:00	<2	<1	<1	<1	<1		MVTL[1]
10/21/08 10:30	<2	<1	<1	<1	<1		MVTL[1]
10/22/08 12:00	<2	<1	<1	<1	<1		MVTL[1]
10/21/08 10:05		ND	ND	ND	ND		NDDH
10/21/08 10:40		ND	ND	ND	ND		NDDH
11/26/08 13:20	<1	<1	<1	<3	<3	<0.2	MVTL
11/26/08 14:20	<1	<1	<1	<3	<3	<0.2	MVTL
12/10/08 10:50	<1	<1	<1	<3	<3	<0.2	MVTL
12/10/08 12:40	<1	<1	<1	<3	<3	<0.2	MVTL

ND - Not detected; report level 0.5 µg/l

[1] MVTL VOC method 465F

APPENDIX E-2

BIODEGRADATION INDICATORS

COC AND SELECTED BIODEGRADATION INDICATORS

		MW-2 08/23/06	MW-2 04/11/07	MW-2 10/09/07	MW-2 04/22/08	MW-2 10/01/08	MW-6 08/23/06	MW-6 04/11/07	MW-6 10/10/07	MW-6 04/22/08	MW-6 10/01/08	MW-7 08/23/06	MW-7 04/11/07	MW-7 10/10/07
MTBE	ppb	<0.5	<1	<1	<1	<1	<0.5	<1	<1	1.4	1.8	<0.5	<1	<1
Benzene	ppb	<0.4	<1	<1	<1	<1	1	7.6	<1	2.6	1.1	<0.4	<1	<1
Toluene	ppb	<0.5	<1	<1	<1	<1	<0.5	1.2	<1	<1	<1	<0.5	<1	<1
Ethyl Benzene	ppb	<0.4	<1	<1	<1	<1	<0.4	<1	<1	<1	<1	<0.4	<1	<1
Xylenes Total)	ppb	<0.6	<3	<3	<3	<3	<0.6	<3	<3	<3	<3	<0.6	<3	<3
Sulfate	mg/l	53.1	64.5	133	213	221	77.7	90	85.6	83.2	95.4	50.7	60	48.9
Nitrate-Nitrite as N	mg/l	<0.1	0.17	<0.1	<0.1	<0.1	<0.1	0.17	<0.1	<0.1	<0.1	<0.1	0.16	<0.1
Ammonia-Nitrogen as N	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	0.23	0.27	0.48	0.56	0.46	<0.1	<0.1	<0.1
Phosphorus P (total)	mg/l	0.14	<0.1	NS	0.24	0.19	0.23	0.13	NS	0.12	0.1	0.15	0.21	NS
COD	mg/l	34	19.9	NS	20.8	17.1	23.7	25.1	NS	20.2	5.1	60.5	18.9	NS
BOD	mg/l	<2	<2	<2	<2	<2	2.93	<6	<2	<2	<2	<2	<2	<2
TOC	mg/l	1.6	3	4.8	2.9	2.7	6.4	3.6	1.9	4.3	4	1.8	2.6	3.2
Fe (total)	mg/l	4.81	5.34	10	9.73	6.14	13.5	7.28	10.7	10.1	8.4	6.61	9.19	5.28
Mn (total)	mg/l	0.64	0.51	0.78	0.75	0.69	1.45	1.03	1.40	1.17	0.92	0.55	0.69	0.47
DO	(mg/l)	1.47	2.68	1.95	10.9	2.08	1.34	2.46	3.08	3.94	1.40	1.37	0.6	1.1
ORP	(mV)	-233.5	54.1	77.1	59.6	19.2	-237.1	-86.3	-40.3	-35.6	100.1	-196.5	-101.6	9.8
EC	(µS/cm)	705	581	645	789	715	877	770	985	853	827	691	542	644
pH		9.48	6.96	7.64	7.94	7.90	9.88	6.94	7.17	7.54	7.35	9.85	7.09	7.26
Temperature	(^{o}C)	9.6	9.1	8.6	9.0	8.2	8.7	9.0	8.4	8.9	7.4	8.4	8.7	8.3

COD - Chemical Oxygen Demand
BOD - Biological Oxygen Demand
TOC - Total Organic Carbon
DO - Dissolved Oxygen
ORP - Oxidation/Reduction Potential
EC - Electrical Conductivity
NS - not sampled. Reduction of monitored biodegradadtion indocators.

COC AND SELECTED BIODEGRADATION INDICATORS (Continued)

		MW-7 04/22/08	MW-7 10/01/08	MW-9 08/23/06	MW-9 04/11/07	MW-9 10/09/07	MW-9 04/22/08	MW-9 10/01/08	MW-10 08/23/06	MW-10 04/11/07	MW-10 10/09/07	MW-10 04/23/08	MW-10 10/01/08
MTBE	ppb	<1	<1	<0.5	<1	<1	<1	<1	7.4	4.2	3.5	7.7	<1
Benzene	ppb	<1	<1	<0.4	<1	<1	<1	<1	55.2	6.4	<1	2	<1
Toluene	ppb	<1	<1	<0.5	<1	<1	<1	<1	<2.5	<1	<1	1.6	<1
Ethyl Benzene	ppb	<1	<1	<0.4	<1	<1	<1	<1	57.6	4.3	<1	<1	<1
Xylenes Total)	ppb	<3	<3	<0.6	<3	<3	<3	<3	<3	<3	<3	<3	<3
Sulfate	mg/l	57	52.4	88.2	108	127	176	455	30.7	49.3	170	189	176
Nitrate-Nitrite as N	mg/l	<0.1	<0.1	0.14	0.12	<0.1	0.21	<0.1	<0.1	<0.1	<0.1	1.41	3.45
Ammonia-Nitrogen as N	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1
Phosphorus P (total)	mg/l	<0.1	0.17	<0.1	<0.1	NS	0.1	0.11	0.39	0.26	NS	0.16	0.14
COD	mg/l	4.7	19.1	8.5	9.9	NS	13.6	65	5.2	25.1	NS	16.6	35.1
BOD	mg/l	<2	<2	5.62	<2	<2	<2	2.24	2.62	<6	<2	<2	<2
TOC	mg/l	2.2	2.3	3.9	2.6	3.5	3.7	4.3	3.7	3.6	2.9	5.4	7.5
Fe (total)	mg/l	3.31	7.99	2.54	2.31	3.8	5.1	3.44	21.1	15.7	1.1	4.3	5.14
Mn (total)	mg/l	0.26	1.08	1.20	0.89	0.73	1.17	1.02	2.25	1.08	0.16	0.32	0.25
DO	(mg/l)	1.3	1.69	4.34	3.67	1.51	15.12	6.26	2.10	0.78	9.39	11.4	12.21
ORP	(mV)	182.4	129.1	-157.0	51.4	107.4	129.4	33.1	-240.1	26.1	173.1	92.6	10.2
EC	(µS/cm)	689	620	794	683	824	760	1236	738	633	745	712	632
pH		7.30	7.66	9.87	7.05	7.81	7.47	8	9.60	7.04	7.73	8.29	8.34
Temperature	(^{o}C)	8.5	7.5	9.5	8.3	10.1	4.5	7.7	8.9	9.8	9.1	8.7	7.8

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TOC - Total Organic Carbon
DO - Dissolved Oxygen
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COC AND SELECTED BIODEGRADATION INDICATORS (Continued)

		MW-11 08/23/06	**MW-11** 05/08/07	**MW-11** 10/09/07	**MW-11** 04/22/08	**MW-11** 09/30/08	**MW-12** 08/23/06	**MW-12** 04/11/07	**MW-12** 10/09/07	**MW-12** 04/23/08	**MW-12** 10/01/08
MTBE	ppb	34.2	7.1	<1	<1	<1	4.8	1.4	<1	<1	<1
Benzene	ppb	297.8	8.3	<1	<1	<1	15.5	5.1	<1	<1	<1
Toluene	ppb	<5	<1	<1	<1	<1	1.2	<1	<1	<1	<1
Ethyl Benzene	ppb	160.1	2.3	<1	<1	<1	1.5	<1	<3	<1	<1
Xylenes Total)	ppb	<6	<3	<3	<3	<3	1.4	<3	<0.2	<3	<3
Sulfate	mg/l	32.9	27.4	257	301	359	64.2	62.5	135	145	278
Nitrate-Nitrite as N	mg/l	<0.1	<0.1	0.35	0.2	<0.1	<0.1	<0.1	<0.1	0.19	2.28
Ammonia-Nitrogen as N	mg/l	1.11	0.37	<0.1	<0.1	<0.1	1.28	0.73	<0.1	<0.1	<0.1
Phosphorus P (total)	mg/l	0.69	0.17	NS	0.56	0.55	0.19	0.15	NS	<0.1	<0.1
COD	mg/l	13.4	13	NS	34.4	53	7.1	11.3	NS	10.9	9.1
BOD	mg/l	2.89	<2	<2	<2	<2	<2	<6	<2	<2	<2
TOC	mg/l	6.6	3.3	2.9	3.6	4.1	5.6	3	<0.5	3.1	3.4
Fe (total)	mg/l	39.8	15.6	33.5	39.4	37	13.8	9.38	1.43	0.65	1.77
Mn (total)	mg/l	1.75	1.54	1.83	2.58	2.28	3.07	1.93	0.24	0.1	0.2
DO	(mg/l)	0.65	1.66	8.80	11.41	11.52	1.66	1.91	13.11	10.6	12.57
ORP	(mV)	-229.9	-33.8	142.2	108.9	131.5	-210.2	22.1	108.7	122.3	8.9
EC	(µS/cm)	1023	764	107	932	922	1023	857	643	665	744
pH		9.56	7.42	7.15	7.81	7.75	9.39	6.56	7.77	8.2	8.2
Temperature	(°C)	9.5	9.1	9.2	9.1	8.3	9.4	8.5	8.94	8.62	7.9

COD - Chemical Oxygen Demand
BOD - Biological Oxygen Demand
TOC - Total Organic Carbon
DO - Dissolved Oxygen
ORP - Oxidation/Reduction Potential
EC - Electrical Conductivity
NS - not sampled. Reduction of monitored biodegradadtion indocators.